CLINICAL RESEARCH

How much energy does the breast fed infant consume and expend?

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Abstract

Energy intake in breast fed infants is uncertain. The doubly labelled water method was used to measure, simultaneously and non-invasively, energy expenditure, energy intake, milk volume intake, energy deposition, and the energy content of breast milk in 12 "free living" breast fed babies at 5 and 11 weeks of age. The validity of this new approach was assessed in a parallel study in 12 formula fed infants. The babies who were exclusively breast fed expended 1.28 and 1.68 MJ/day at five and 11 weeks and had intakes of 1.81 and 2.22 MJ/day; these intakes were associated with normal growth but were well below those recommended previously. At five and 11 weeks the calculated energy content of breast milk was 0.24 and 0.25 MJ/100 ml, which is substantially lower than that commonly reported in milk obtained unphysiologically by expression of the breast.

These data cast doubt on the widely used published standards for infant feeding.

Introduction

Reliable data on the energy intake and energy expenditure of breast fed babies have been difficult to obtain. Energy intake from breast milk has been taken as a standard in infant nutrition,¹ and published values for the energy content of expressed milk are used as a model by manufacturers of infant formulas. The usual means of assessing dietary energy is by obtaining samples of breast milk by unphysiological manual or mechanical breast expression; this approach, however, is flawed by methodological problems and by the inconstant composition of human milk. Data on energy expenditure have important applications in infant nutrition and would provide a

basis for future investigation of nutritional and metabolic disorders of early childhood.

Traditional methods of measuring energy expenditure (direct and indirect calorimetry) entail harnessing the subject to apparatus for prolonged periods and, except when used during sleep, require isolation of the child from its parents. Methods of measuring energy expenditure in "free living" subjects, such as activity scoring and heart rate monitoring, are subject to uncertain error. In this study we adopted a new approach to this type of investigation. Using the doubly labelled water method (oral administration of water labelled with two naturally occurring stable isotopes, deuterium and oxygen-18),² we estimated, simultaneously and non-invasively, energy expenditure, metabolisable energy intake, milk intake, and the energy content of breast milk consumed in free living subjects.

Subjects and methods

Twelve healthy and exclusively breast fed infants (five boys, seven girls) were studied at home for seven day periods at 4–6 weeks and again at 10–12 weeks (midpoints five and 11 weeks); measurements were made by the doubly labelled water method described below. In addition, data from 12 exclusively formula fed infants, studied at the same postnatal ages, were included to validate the isotope method for measuring the energy density of the feed. The formula, which was prepared for the study by Farley Health Products Ltd, had an energy density of 0.28 MJ/100 ml. The study was approved by the ethical committees of the Cambridge Health Authority and the nutrition unit.

The principle of the doubly labelled water method, first developed by Lifson *et al* for use in small mammals,² is that two stable isotopes of water (H_2^{18}O and $^2\text{H}_2\text{O}$) are administered simultaneously and their initial enrichment in a body fluid and subsequent rates of disappearance from this fluid are monitored by isotope ratio mass spectrometry. The initial enrichment of either isotope reflects body water pool size (from the principle of dilution) and permits an estimation of body composition. Subsequently, the rate of disappearance of $^2\text{H}_2\text{O}$ reflects water output (and hence water intake) while that of H_2^{18}O reflects water output plus production of carbon dioxide because ^{18}O is free to interchange between water and carbon dioxide through the action of carbonic anhydrase. The difference between the two rates of disappearance is, therefore, a measure of the rate of production of carbon dioxide. With additional knowledge of the subject's respiratory quotient (measured or derived from previous studies on a similar population or calculated from the composition of food intake) energy expenditure can be calculated.³ Details of the method and principles of the calculations used are reported elsewhere.⁴ Specific details are discussed below.

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Two samples of urine or saliva were obtained from each infant before the isotope study to measure natural concentrations of ^2H and ^{18}O in a body fluid.⁵ An accurately weighed dose of sterile isotope solution providing roughly $0.28 \text{ g H}_2^{18}\text{O}$ and $0.1 \text{ g H}_2^{2}\text{O}$ per kg body weight was given orally.⁶ Subsequently samples of the same body fluid were collected at four and five hours and then daily for seven days (a period that ensured two to three biological half lives of the isotopes).

Total body water at the start of each study period was calculated by isotope dilution as described previously.⁴ To calculate energy expenditure the respiratory quotient was taken to be 0.85 (a value close to that measured by us by calorimetry in infants of similar age (see discussion)). On the basis of water balances (unpublished data) we took a figure of 13% of water output as being subject to fractionation (evaporative loss).

Metabolisable energy intake (energy absorbed) is energy stored plus energy expended. To calculate energy stored two assumptions were made. Firstly, the decline in total body water (percentage weight) from the start of the study at five weeks to the start of the study at 11 weeks was assumed to be linear in each subject (the data of Fomon *et al* suggest a near linear decline at this age⁷); thus total body water at the end of each one week study period could be calculated. Secondly, published values were used for the water and protein contents of lean body mass: 80.4% and 15.2%, respectively, at five weeks and 80.0% and 15.7% at 11 weeks (data on both sexes combined).⁷ These numerical assumptions are less critical than might be supposed as the data are used to detect a change in body composition during the study and not an absolute value.

The increases in body fat, lean body mass, and protein over the seven day study periods were calculated as follows: lean body mass at start or end of study = body weight $\times$ total body water/proportion of water in lean body mass; body fat = body weight - lean body mass; fat accretion = difference in body fat between start and end of period; protein accretion = lean body mass gain $\times$ (published) proportion of protein in lean body mass. Conversion factors (9.25 for fat and 5.6 for protein) were used to derive energy stored as fat and protein during each study (carbohydrate storage was assumed to be negligible).

Milk intake was calculated from the value for water intake determined isotopically, taking account of the water content of breast milk (from published values, 87.5%), with adjustments made for the water derived from complete oxidation of its fat, carbohydrate, and protein and for the water in fat and protein stored in new tissue (as derived above). The maximum estimated error in values for milk intake from the assumed water content of breast milk was under 0.2%. The metabolisable energy content of breast milk (MJ/100 ml) was calculated as metabolisable energy intake (MJ/day) / milk volume intake (100 ml/day). Statistical comparisons were made with Student's *t* test (paired).

Results

The table shows a summary of data obtained in the breast fed infants; it

Growth, total body water, energy deposition, energy expended, metabolisable energy intake, milk intake, and energy content of breast milk measured by doubly labelled water method in 12 exclusively breast fed infants at 5 and 11 weeks of age. Figures are means (SE)

	5 Weeks	11 Weeks	95% Confidence interval for differences
Anthropometric variables at start of study period:			
Weight (g)	4497 (107)	5589 (113)	
Head circumference (cm)	38.5 (0.3)	40.6 (0.3)	
Length (cm)	55.4 (0.5)	59.3 (0.5)	
Weight gain (g/day)	36.3 (2.5)	25.6 (3.1)**	
Total body water (% body weight)†	69.2 (1.1)	64.9 (1.4)**	-6.8 to -1.8
Energy deposited in new tissue:			
As protein (MJ/day)	0.09 (0.01)	0.05 (0.01)**	-15 to -5
As fat (MJ/day)	0.43 (0.07)	0.49 (0.10)	-11 to 37
Total:			
MJ/day	0.52 (0.06)	0.54 (0.10)	-24 to 30
MJ/kg/day	0.12 (0.01)	0.10 (0.02)*	-9 to -1
Energy expended:			
MJ/day	1.28 (0.11)	1.68 (0.08)*	32 to 156
MJ/kg/day	0.28 (0.03)	0.30 (0.01)	-9 to 17
Metabolisable energy intake‡:			
MJ/day	1.81 (0.14)	2.22 (0.13)*	25 to 171
MJ/kg/day	0.40 (0.03)	0.39 (0.03)	-34 to 30
Milk intake (ml/day)	767 (20)	868 (39)*	30 to 172
Energy content of milk (MJ/100 ml)	0.24 (0.02)	0.25 (0.02)	-4 to 12

† Measured by deuterium dilution. ‡ Energy deposited plus energy expended. * $p < 0.05$,

** $p < 0.01$ by paired *t* test.

documents birth weight, body weight at the two study periods (midpoints five and 11 weeks), and rate of weight gain during the two periods of study. Total body water (by deuterium dilution) at the start of the two study periods fell significantly ($p < 0.02$).

Energy expenditure rose from 1.28 (SE 0.11) to 1.68 (0.08) MJ/day ($p < 0.01$), but when expressed on a per kg basis this rise was not significant. Energy stored as protein fell significantly ($p < 0.05$), though energy stored as fat remained constant. Total energy stored as fat plus protein was also similar at five and 11 weeks. Metabolisable energy intake (energy expended plus energy stored) rose significantly ($p < 0.05$). The proportion of metabolisable energy intake stored was 29% at five weeks and 24% at 11 weeks.

Milk intake rose from 767 (20) to 868 (39) ml/day ($p < 0.02$). The calculated metabolisable energy density of breast milk (metabolisable energy intake/milk volume intake) was 0.24 (0.02) MJ/100 ml at five weeks and 0.25 (0.02) MJ/100 ml at 11 weeks.

At 11 weeks the mean energy density of the formula, 0.28 (0.02) MJ/100 ml, measured by the same isotope procedure and assumptions as for the breast fed group, was the same as the value for metabolisable energy density quoted by the manufacturers (0.28 MJ/100 ml calculated from nutrient composition). It is not possible, however, to estimate the precision on the difference between our mean value for energy intake from the formula derived by the isotope method and the corresponding value based on the manufacturer's quoted figures for energy density of the formula; our values represent the mean of measured absorbed energy in individual infants, whereas the manufacturer's value is based on generalised assumptions concerning the standard conversion factors used to calculate metabolisable (absorbed) energy from nutrient composition. These conversion factors might not apply to individual infants, who vary in their absorption of energy. Thus the comparison presented should be taken as a guide to the validity of the isotope procedure for measuring metabolisable energy intake rather than as a definitive validation study, and further work is planned. At five weeks the energy content of the formula derived by the isotope method was 0.26 (0.02) MJ/100 ml.

Discussion

Information on energy intake and energy expenditure has a wide application in physiological, epidemiological, and clinical studies. In early infancy (when the breast fed infant has been taken as a model for performance) there has, however, been a lack of suitable research tools for such work. Recently the doubly labelled water method has been developed,⁸⁻¹² and we showed that this method provides accurate information on energy expenditure and water (and therefore milk) intake in fast growing infants (in whom special account must be taken of deposition of water during growth and of isotopic fractionation of insensible loss of water).⁴ We were able to provide new information on energy intakes and expenditure in healthy breast fed infants and on the energy content of breast milk consumed.

Breast fed babies in the free living state expended 1.28 MJ/day at five weeks and 1.68 MJ/day at 11 weeks (0.28 and 0.30 MJ/kg/day, respectively). These data will have applications in future studies designed to identify abnormalities in energy metabolism in disease or growth failure at this age. At the two ages studied a further 0.52 and 0.54 MJ/day, respectively, were stored during growth, and therefore metabolisable energy intake (energy expended plus energy stored) was 1.81 and 2.20 MJ/day. Though these infants showed satisfactory growth, with mean weight, length, and head circumference at five and 11 weeks lying above the 50th centile (standards of the National Centre for Health Statistics),¹³ their energy intakes were substantially below those recommended previously. In 1973 the Food and Agriculture Organisation and World Health Organisation recommended an intake of 0.50 MJ/kg (120 kcal/kg) at the ages we studied¹⁴; in 1985 this recommendation was changed to 0.49 MJ/kg (116 kcal/kg).¹⁵ In contrast, our values for metabolisable energy intake were 0.40 and 0.39 MJ/kg/day (95 and 93 kcal/kg/day) at five and 11 weeks, respectively. Others have commented on the comparatively low energy consumption of breast fed babies; Whitehead and Paul derived corresponding intakes of around 0.44 and 0.40 MJ/kg/day,^{16 17} but they used published data on expressed breast milk and for the reasons given below even these low values might be expected to be overestimates.

Average milk intakes in this study (767 and 868 ml/day at five and 11 weeks, respectively, or 165 and 150 g/kg) were well within the

range of reported values¹⁸ and consistent with values from this unit for a population selected for exclusive breast feeding for three months. Thus the low energy intake of breast fed babies was due to the low energy content of breast milk rather than to a low volume intake. Previously, energy intake from breast milk has been estimated by matching data on milk volume intake, obtained by test weighing or giving deuterium to the mother or infant,^{19,21} with information on the energy content of expressed breast milk. Though milk volume intake may be calculated with satisfactory accuracy,²¹ it has been difficult to obtain representative samples of expressed breast milk, which varies in its fat and therefore energy content diurnally and during the course of the feed.²² Moreover, Lucas *et al* speculated that milk obtained unphysiologically by manual or mechanical expression might not have the same composition as milk consumed during breast feeding itself (so called suckled breast milk).²³ This would be the case, for instance, if the infant did not normally consume all the high fat hindmilk that could still be removed by expression. Subsequently, two studies that used a nipple shield sampling system to obtain suckled breast milk directly indicated that expressed breast milk may overestimate the energy density of suckled breast milk.^{22,24}

Our new approach here to the measurement of the energy density of breast milk was to divide metabolisable energy intake by milk volume intake, both of which had been measured by the isotope studies, thus avoiding the problem of milk sampling. No apparatus was interposed between mother and infant and no investigator was present during breast feeding—both factors that might interfere with normal lactation. At 11 weeks our mean value for breast milk energy content was 0.25 MJ/100 ml (61 kcal/100 ml); this is substantially lower than the figure usually cited for expressed breast milk. The mean value obtained by the same method for the formula fed group, however, was the same as the figure quoted by the manufacturer (0.28 MJ/100 ml (68 kcal/100 ml)) for the metabolisable energy density of the formula calculated from its nutrient composition. (Further validation is required; this is being undertaken currently.) At five weeks the estimated energy content in breast milk 0.24 MJ/100 ml (57 kcal/100 ml) was even lower; similarly the metabolisable energy density of the formula at five weeks derived by the isotope method was slightly lower than that at 11 weeks. Though neither difference reached significance, it is possible that absorption of dietary energy was less complete at five weeks.

We considered that the low mean energy density of breast milk derived here might have related to error in the key assumptions used. We assumed that the respiratory quotient was 0.85 and the proportion of water output liable to fractionation 13%. Both these values, however, are low, as the respiratory quotient may be as high as 0.88 and fractionated water losses 20%. Such an adjustment in either value would have resulted in an even lower calculated milk energy content (3% reduction in each case).

It was impossible to compare simultaneously breast milk energy content obtained by our techniques and that derived by expression of milk as this would have meant disruption of normal feeding. Many investigators,¹ however, have examined the composition of expressed breast milk (Macy *et al* reviewed 1500 papers on the subject in 1953²⁵). A recent study by the Department of Health and Social Security derived a value of 0.29 MJ/100 ml (70 kcal/100 ml); other key previous reports have quoted values ranging from 0.27 MJ/100 ml (64 kcal/100 ml) to 0.33 MJ/100 ml (80 kcal/100 ml).²⁵⁻³⁰ Given the technical problems of milk sampling published values would be expected to be variable, and very low fat and energy values may be obtained if milk for analysis is not thoroughly mixed immediately before sampling. Nevertheless, this weight of evidence suggests a mean value for expressed breast milk of at least 0.29 MJ/100 ml, which lies above the upper limit of the 95% confidence interval for values obtained here (0.24 to 0.25 MJ/100 ml).

The doubly labelled water method is non-invasive, requiring only

a small oral dose of (non-radioactive) labelled water and collection of urine or saliva. The fairly long study period minimises errors due to day to day variation in nutrient intake or activity. We have shown the potential of this method in studies of infant and childhood nutrition that have previously been difficult to undertake. This initial study suggests that previous estimates of energy requirements in healthy babies may have been too high and that the traditional model in infant nutritional research, expressed breast milk, may not be the most appropriate one on which to base recommendations for energy intake or provide guidance for manufacturers of infant formulas.

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