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Energy requirements of infants

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Abstract

Objective: To estimate the energy requirements of infants from total energy expenditure and energy deposition during growth.
Design: Energy requirements during infancy were estimated from total energy expenditure measured by the doubly labelled water method and energy deposition based on measured protein and fat gains.
Setting: Database on the total energy expenditure and energy deposition of infants was compiled from available studies conducted in China, Chile, Gambia, Mexico, Netherlands, UK, and USA.
Subjects: Healthy, term infants.
Results: Total energy requirements (kJ day^{-1}) increased with age and were higher in boys than girls due to differences in weight. Energy requirements decreased from 473 kJ kg^{-1} per day for boys and 447 kJ kg^{-1} per day for girls at 1 month of age to 337 kJ kg^{-1} per day for boys and 341 kJ kg^{-1} per day for girls at 6 months of age, and thereafter tended to plateau. Energy deposition as a percentage of total energy requirements decreased from 40% at 1 month to 3% at 12 months of age. These estimates are 10–32% lower than the 1985 FAO/WHO/UNU recommendations which were based on observed energy intakes of infants.
Conclusions: Recommendations for the energy intake of infants should be revised based on new estimates of total energy expenditure and energy deposition.

Keywords
Metabolizable energy
Basal metabolism
Physical activity
Total energy expenditure
Energy cost
Infants
Growth
Energy deposition

Introduction and historical background

In the 1985 FAO/WHO/UNU publication, *Energy and Protein Requirements*[1], the energy requirement of an individual is defined as 'the level of energy intake from food that will balance energy expenditure when the individual has a body size and composition, and level of physical activity, consistent with long-term good health; and that will allow for the maintenance of economically necessary and socially desirable physical activity. In children and pregnant or lactating women the energy requirement includes the energy needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.' To the extent possible, the recommendations incorporated the following concepts:

1. The energy needs of a group are represented by the average of the needs of individuals in that group. Most individuals have the ability to self-select their food intake in accordance with their energy requirement over the long term, since it is believed that regulatory mechanisms operate to maintain a balance between energy intake and energy requirement over long periods of time. One would expect a correlation between energy intake and energy requirement among individuals if sufficient food is available in the absence of interfering factors. 'For the requirement of classes, the estimate of average requirement is an appropriate descriptor for the distribution of requirement[1].'
2. 'As a matter of principle, we believe that estimates of energy requirements should, as far as possible, be based on estimates of energy expenditure, whether actual or desirable. To determine requirements from observed intakes is largely a circular argument, since in both developing and developed countries actual intakes are not necessarily those that maintain a desirable body weight or optimal levels of physical activity, and hence health in its broadest sense. However, it has not been possible to follow this principle in the case of children, because we do not have enough information about their energy expenditure[1].'

The first concept, that the energy needs of a group are represented by the average energy requirement of individuals in that group, is applicable to infants. There is evidence that energy intake is self-regulated[2,3], and most probably matches energy requirements. In the 1996 IDECG publication, *Energy Requirements of Infants*[4], the second

*Corresponding author: Email nbutte@bcm.tmc.edu concept was upheld and an argument was made for revision of the 1985 FAO/WHO/UNU recommendations based on energy expenditure. The 1985 FAO/WHO/UNU recommendations for infants were based on a compilation of energy intakes of infants predating 1940 and up to 1980, representing 9046 data points[5]. Data analysis revealed a highly curvilinear relationship between energy intake per kg body weight and age in months. Because of the concern for a secular trend in infant feeding practices, i.e. different formulations of breast milk substitutes and later introduction of complementary foods, the energy intakes of well-nourished infants recorded after 1980, representing 3573 data points, were examined[4]. The best equations describing energy intake of infants were:

$$\begin{aligned}\text{Energy intake (kJ day}^{-1}) = {}& 879 - 248\,\text{Age (months)} + \\ & 156\,\text{Feed type} + 264\,\text{Weight (kg)} + \\ & 58\,\text{age} \times \text{Feed type} + 23\,\text{age} \times \text{weight}\end{aligned}$$

$r^2 = 0.80$; $n = 422$

$$\begin{aligned}\text{Energy intake (kcal day}^{-1}) = {}& 210 - 59.2\,\text{Age (months)} + \\ & 37.2\,\text{Feed type} + 63.1\,\text{Weight (kg)} + \\ & 14.0\,\text{age} \times \text{Feed type} + 5.6\,\text{age} \times \text{weight}\end{aligned}$$

$r^2 = 0.80$; $n = 101$

where Feed type is coded 0 for breast-fed and 1 for formula-fed.

Although evidence for a strong secular trend in energy intakes of infants was not found, energy intakes recorded after 1980 were found to be 2–15% lower than the 1985 FAO/WHO/UNU recommendations[1], partially due to the 5% increment added to the recommendations to account for presumed underestimation of intake, and partially due to changes in infant feeding practices. The 1985 FAO/WHO/UNU recommendations did not reflect current observations of energy intake of infants.

Energy expenditure was not used to derive energy recommendations, not because information on BMR of infants was not available, but because reasonable allowances for physical activity were undefined. In the IDECG publication[4], it was proposed that total energy expenditure (TEE) by the doubly labelled water (DLW) method could be used as the basis for new recommendations, with the strong caveat that data were limiting for the second 6 months of life. Of the 268 TEE data points of well-nourished infants, 90% of the values were on infants under 6 months of age.

Derivation of the energy requirements of infants also requires an estimate of the energy requirement for growth. In the IDECG report[4], the energy cost of growth (ECG) was based upon median weights from the 1977 NCHS growth curves, and weight velocities and rates of fat and protein deposition estimated by Fomon *et al.*[6] The total ECG declined throughout infancy from 25 kJ g^{-1} (5.9 kcal g^{-1}) at 1–2 months to 14 kJ g^{-1} (3.4 kcal g^{-1}) at 9–12 months. In the 1985 FAO/WHO/UNU report[1], a value of 23 kJ g^{-1} (5.6 kcal g^{-1}) gained was suggested for healthy term infants.

In the IDECG report[4], total energy requirements were based on TEE plus energy deposition and found to be 9–39% lower than the FAO/WHO/UNU recommendations[1]. Expansion of the DLW database on TEE of infants in terms of sample size, age range and geographic distribution across the entire age range of infancy was recommended at that time.

Energy requirements of infants

Components of the energy requirement during infancy

Energy requirements during infancy are equal to the sum of TEE and ECG. TEE may be partitioned into further components, i.e. basal metabolism, thermic effect of feeding (TEF), thermoregulation and physical activity. Direct calorimetry and respiratory gas exchange, also referred to as indirect calorimetry, have been used to measure the energy expenditure of infants.

Energy balance

The energy balance equation in infants is described as:

$$\text{Gross energy intake} = \text{energy excreted} + \text{energy expended} + \text{energy stored}$$

Gross energy intake measured by combustion in a bomb calorimeter exceeds the energy available to the infant, since most foods are not completely absorbed and protein is oxidised incompletely. Fecal fat excretion, which depends on the type of milk and age of the infant, accounts for most of the energy losses. Fat is remarkably well absorbed from human milk; fat excretion ranges from 7.7 to 13.4% of intake in newborn infants, and 5% beyond the newborn period[7]. Fat excretion from cows' milk and infant formula are highly variable (5–37%) and dependent on the fat source. The gross energy values for milk (5.65 kcal g^{-1} protein, 3.95 kcal g^{-1} carbohydrate and 9.25 kcal day^{-1} fat) may be used to estimate the gross energy intake[8].

Metabolizable energy is defined as digestible energy minus the heat of combustion of urine. Atwater's energy values of 4 kcal g^{-1} protein or carbohydrate and 9 kcal g^{-1} have been used to convert the macronutrient composition of infant formulas to metabolizable energy. Application of the adult-derived Atwater's values to infant diets is satisfactory if the dietary fat is highly digestible and protein concentration modest. Because of higher excretory losses of nitrogenous substances and fat, metabolizable energy from higher protein formulas and cows' milk may be overestimated. Complete energy balance studies are limited in term infants; metabolizable energy averaged 92% in infants fed breast milk or cows' milk preparations[9].

Basal metabolism

Basal metabolic rate (BMR) is defined as the energy expended to maintain cellular and tissue processes fundamental to the organism. Specifically, it is the energy needed to maintain body temperature, support the minimal work of the heart and respiratory muscles, and supply the energy requirements of tissues at rest. The basal metabolism of infants is accounted for primarily by the brain, liver, heart, and kidney[10]. The contribution of the brain to basal metabolism is exceptionally high in the newborn period (70%) and throughout the first years of life (60–65%).

Conventionally, BMR is measured under standard conditions whereby the individual is at rest in a thermoneutral environment after a 12–18 hour fast. The application of these criteria to infants would be impractical; thus, investigators have adopted various approaches to measure 'basal metabolism' in sleeping infants[11]. Some investigators have used sedatives to induce sleep[12]; others have opted to feed the infant[13]. Sleep and some sedatives will lower BMR, whereas feeding will augment it.

Basal metabolism of term infants has been investigated extensively[12,13]. Reported BMR ranges from 180 to 251 $\mathrm{kJ\,kg^{-1}}$ per day (43–60 $\mathrm{kcal\,kg^{-1}}$ per day). The high variability is attributable to biological differences in body composition, and technical differences in experimental conditions and methods. Schofield *et al.* compiled ~300 measurements from historical data to develop predictive models based on weight and length[14]. The prediction equations for BMR of healthy children under the age of 3 years are as follows:

$$\text{Boys: BMR (MJ day)} =$$
$$0.0007\,\text{Weight (kg)} + 6.349\,\text{Length (m)} - 2.584;$$
$$r = 0.97,\ \text{SEE} = 0.24$$

$$\text{Girls: BMR (MJ day)} =$$
$$0.068\,\text{Weight (kg)} + 4.281\,\text{Length (m)} - 1.730;$$
$$r = 0.97,\ \text{SEE} = 0.22$$

$$\text{Boys: BMR (kcal day}^{-1}) =$$
$$0.1673\,\text{Weight (kg)} + 1517\,\text{Length (m)} - 618;$$
$$r = 0.97,\ \text{SEE} = 57$$

$$\text{Girls: BMR (kcal day}^{-1}) =$$
$$16.25\,\text{Weight (kg)} + 1023\,\text{Length (m)} - 413;$$
$$r = 0.97,\ \text{SEE} = 52$$

These equations have been evaluated in more recent investigations, and have been found to underestimate BMR at early ages. The influence of neonatal age and sedation on the measurements of BMR might explain the lower values predicted by the Schofield equation compared with more recent measurements. Butte *et al.*[11,16] measured Sleeping BMRs (SMR) in a series of 76 infants during the first 2 years of life. BMR predicted from weight and length using the Schofield equation[14] was equal to 0.88 SMR at 3–12 months, 0.93 SMR at 18 months and 1.00 SMR at 24 months. Prediction equations for SMR were developed as follows[16]:

$$\text{SMR (MJ day}^{-1}) = -1.20 - 0.009\,\text{Age (months)} -$$
$$0.061\,\text{Sex} + 0.132\,\text{Feed type} + 0.122\,\text{Weight (kg)} +$$
$$0.032\,\text{Length (cm)} - 0.010\,\text{Feed type} \times \text{Age};$$
$$r = 0.88,\ \text{SEE} = 0.21$$

$$\text{SMR (kcal day}^{-1}) = -287 - 2.15\,\text{Age (months)} -$$
$$14.6\,\text{Sex} + 31.5\,\text{Feed type} + 29.2\,\text{Weight (kg)} +$$
$$7.6\,\text{Length (cm)} - 2.4\,\text{Feed type} \times \text{Age};$$
$$r = 0.88,\ \text{SEE} = 50$$

where sex is coded 1 for boys and 2 for girls, and feed type is coded 1 for breast-fed and 2 for formula-fed.

Wells[17] also reported poor agreement between measured SMR and BMR predicted by the Schofield equation[14]. The percentage error was −13, −8, −5, −7, and −1% at 1.5, 3, 6, 9, and 12 months of age. Prediction equations for SMR were also developed on 40 infants in the first year of life[17]:

$$\text{Boys: log SMR (MJ day}^{-1}) =$$
$$0.378\,\text{log Weight (kg)} + 1.55\,\text{log Length (m)} - 6.72;$$
$$r = 0.88,\ \text{SEE} = 0.17$$

$$\text{Girls: log SMR (MJ day}^{-1}) =$$
$$0.427\,\text{log Weight (kg)} + 1.16\,\text{log Length (m)} - 5.23;$$
$$r = 0.85,\ \text{SEE} = 0.16$$

$$\text{Boys: log SMR (kcal day}^{-1}) =$$
$$90\,\text{log Weight (kg)} + 370\,\text{log Length (m)} - 1606;$$
$$r = 0.88,\ \text{SEE} = 41$$

$$\text{Girls: log SMR (kcal day}^{-1}) =$$
$$102\,\text{log Weight (kg)} + 277\,\text{log Length (m)} - 1250;$$
$$r = 0.85,\ \text{SEE} = 38$$

Thermic effect of feeding

The energy expended above basal metabolism in response to feeding, or the thermic effect of feeding, is referred to as the TEF. The TEF amounts to approximately

10% of the daily energy expenditure[18]. The major part of the rise in energy expenditure after a meal is due to the metabolic costs of transporting and converting the absorbed nutrients into their respective storage forms. The TEF in preterm infants[19] and in infants recovering from malnutrition[20] has been shown to be proportional to the rate of weight gain. These observations support the view that the increased energy expenditure is due to the metabolic costs of tissue synthesis.

Thermoregulation

Thermoregulation constitutes an additional energy cost when infants are exposed to temperatures below and above their zone of thermoneutrality. The environmental temperature at which oxygen consumption and metabolic rate are at their lowest is described as the thermoneutral zone[21]. In the first 24 hours after birth, this temperature is 34–36°C for the naked infant and falls to 30–32° by 7–10 days of age. The amount of energy required to maintain normal body temperature is greater at lower than at higher temperatures. At temperatures below the critical temperature, i.e. the lower end of the thermoneutral zone, energy expenditure increases proportionately to the drop in environmental temperature.

The neonate responds to cold exposure with an increase in metabolic rate, which is thought to be mediated by increased sympathetic tone. Neonatal heat production occurs mainly by non-shivering thermogenesis[22]. Oxidation of brown adipose tissue located between the scapulae, in the posterior triangle of the neck, and around major vessels and organs of the mediastinum and abdomen, is thought to make the most important contribution to non-shivering thermogenesis in infants.

Physical activity

Physical activity represents a component of TEE that increases as the infant grows and develops. Up until recently, the energy cost of activity could be estimated from a very limited set of infant data. Using respiratory calorimetry, 24-hour energy expenditure was measured in two term breast-fed infants, 3 and 6 months of age[23]. Twenty-four-hour energy expenditure rates, 310 and 293 kJ kg^{-1} per day (74 and 70 kcal kg^{-1} per day), were only 20–30% above basal. Talbot suggested adding 15, 25, and 40% to basal metabolic rates to cover the activity needs of very quiet, normally active, and extremely active infants, respectively[23]. Based on calorimetric studies of 70 healthy, full-term infants, Benedict and Talbot[13] estimated that activity may represent as much as 40% of TEE. The peak of energy expenditure of activity occurred at 6 months; thereafter, voluntary muscular control became more coordinated, and the energy expenditure more efficient.

The DLW technique combined with calorimetry allows an estimate of activity energy expenditure (AEE). Energy expended on physical activity may be estimated from the difference between TEE and BMR, since most BMR measurements have been made in the fed state and because growth is thought to be a continuous process, the BMR includes the thermic effect of feeding and the energy cost of tissue synthesis. Wells *et al.*[15] reported AEE was 22% of TEE in 3 month old infants. In a longitudinal study, AEE increased from 270 kJ day^{-1} (64 kcal day^{-1}) at 3 months to 1124 kJ day^{-1} (269 kcal day^{-1}) at 24 months[16]. Physical activity level (PAL) increased from 1.2 at 3 months to 1.4 at 24 months of age.

Lower levels of activity have been reported in undernourished infants and children[24]. Activity levels of infants studied in The Gambia were lower than those of a comparable group in the UK; differences, however, were attributed to socio-cultural factors rather than differences in nutritional status.

Total energy expenditure

TEE of infants encompasses basal metabolism, thermoregulation, physical activity, and the synthetic cost of growth. The DLW method, which has been validated in preterm infants and hospitalised term infants, may be used to measure TEE in infants. In the validation studies, mean errors between the DLW method and respiration calorimetry were 0.3 ± 2.6%[25], −0.9 ± 6.2%[26], −4.5 ± 6.0%[27], and −0.4 ± 11.5%[28].

Published mean data on the TEE of infants living in developed and developing countries are summarised in Table 1. Standardised by weight, TEE ranged from 255 to 393 kJ kg^{-1} per day (61–94 kcal kg^{-1} per day), increasing linearly with age. TEE of breast-fed infants was shown to be lower than formula-fed infants[16,29–31]. Energy expenditure was 12, 7, 6, 3, 0 and 1% higher in formula-fed than breast-fed infants at 3, 6, 9, 12, 18 and 24 months, respectively, indicating that differences in TEE between feeding groups diminish beyond the first year of life[16].

Several published TEE studies are available on presumably well-nourished infants living in developed countries (Table 1). Individual TEE data were available for further analysis from the study published by Butte *et al.*[16] These TEE data were on 76 healthy infants ($n = 40$ breast-fed and $n = 36$ formula-fed infants) studied longitudinally throughout the first 2 years of life[16]. The linear relationship between TEE and weight is graphically displayed in Fig. 1, with 95% prediction and confidence intervals. The coefficient of variation was fairly uniform across age: 21.0, 18.0, 15.4, 17.7, 17.7 and 16.0% at 3, 6, 9, 12, 18 and 24 months, respectively. TEE differed by age, sex (boys > girls) and feeding group (formula-fed > breast-fed). TEE was significantly affected by weight and height. Because of the high correlations between age, weight and height ($r = 0.91$–0.96), they were all good predictors

Table 1 Database for total energy expenditure (TEE) of infants by doubly labelled water method

Reference	*n*	Age (months)	Weight (kg)	Height (cm)	FFM (kg)	FM (%WT)	TEE (kcal day^{-1})	TEE (kJ day^{-1})	TEE (kcal kg^{-1} per day)	TEE (kJ kg^{-1} per day)	Comments
First year of life											
Lucas, 1987[51]	12BF	0.9–1.4	4.5 (0.1)[a]	55.4 (0.5)			306 (90)	1280 (381)	67 (24)	280 (104)	BF infants, Cambridge, UK
	12BF	2.3–2.8	5.6 (0.1)	59.3 (0.5)			402 (66)	1680 (277)	72 (10)	300 (35)	
Vasquez-Velasquez, 1987[52]	8	0–3	4.6				381 (88)	1594 (368)	82 (23)	343 (96)	MF Gambian infants
	15	3–6	6.1				473 (106)	1979 (444)	78 (21)	326 (88)	
	19	6–9	7.2				572 (121)	2393 (506)	80 (16)	335 (67)	
	8	9–12	7.8				664 (133)	2778 (556)	85 (12)	356 (50)	
Roberts, 1988[53]	18	3	5.7				408 (28)	1707 (117)	72 (5)	301 (21)	MF infants, Cambridge, UK TEE/SMR = 1.15
Davies, 1989, 1991[54,55]	20BF	1.4	4.6				283 (80)	1184 (335)	61 (18)	255 (75)	BF and FF infants, Cambridge, UK
	29FF	1.4	4.5				319 (97)	1335 (406)	71 (19)	297 (79)	
	20BF	2.8	5.7				366 (73)	1531 (305)	64 (13)	268 (54)	BF and FF infants, Cambridge, UK
	30FF	2.8	5.8				433 (118)	1812 (494)	75 (20)	314 (84)	
	19BF	6.0	7.6				590 (119)	2468 (498)	78 (14)	326 (58)	BF and FF infants, Cambridge, UK
	18FF	6.0	7.8				619 (78)	2590 (326)	79 (11)	330 (46)	
	12BF	9.2	8.4				702 (124)	2937 (519)	83 (15)	347 (68)	BF and FF infants, Cambridge, UK
	10FF	9.2	8.6				808 (184)	3381 (770)	94 (21)	393 (88)	
Butte, 1990[29]	10BF	1	4.6 (0.7)	54.8 (2.4)			291 (48)	1218 (201)	64 (7)	268 (29)	BF and FF infants, Houston, TX
	10FF	1	4.8 (0.3)	55.0 (1.2)			316 (42)	1322 (176)	67 (8)	280 (33)	TEE/SMR = 1.28, 1.26
	10BF	4	6.6 (0.7)	62.4 (2.0)			420 (49)	1757 (205)	64 (8)	268 (33)	TEE/SMR = 1.34, 1.36
	10FF	4	6.6 (0.6)	61.6 (1.6)			476 (58)	1992 (243)	73 (9)	305 (38)	
Butte, 1993[32]	19BF	4	5.9 (0.8)	60.2 (2.1)	4.8 (0.7)	20.8 (6.5)	446 (97)	1866 (406)	74 (14)	310 (58)	BF infants, Capulhuac, Mexico
	19BF	6	7.1 (0.8)	64.8 (2.1)	5.8 (0.6)	18.0 (5.2)	542 (83)	2268 (347)	76 (7)	318 (29)	
Wells, 1995[15]	18BF	1.5	6.2 (0.7)	61.3 (1.9)	4.4 (0.4)	27.4 (6.8)	454 (72)	1900 (301)	74 (10)	310 (42)	BF and FF infants, Cambridge, UK
	20FF	1.5	6.0 (0.6)	60.9 (1.5)	4.5 (0.5)	23.8 (6.5)	464 (90)	1941 (376)	78 (14)	326 (58)	
Wells, 1996[56]	92	1.5	5.9 (0.6)	59.9 (2.1)	4.5 (0.5)	23.4	430 (101)	1799 (422)	73.0	305	Cambridge, UK
Davies, 1997[57]	7M	9	10.2 (0.8)	74.4 (2.6)		28.0 (5.5)	751 (160)	3142 (669)	74 (13)	310 (54)	Cambridge, UK
	9F	9	8.6 (0.8)	72.3 (1.4)		30.4 (8.0)	623 (100)	2607 (418)	73 (15)	305 (63)	
	10M	12	10.9 (1.3)	78.3 (3.8)		24.7 (5.0)	833 (104)	3485 (435)	77 (14)	322 (58)	
	8F	12	9.4 (0.8)	75.3 (3.2)		25.0 (9.8)	729 (143)	3050 (598)	78 (15)	326 (63)	
de Bruin, 1998[35]	34	1	4.4		3.7 (0.4)	14.6 (3.3)	306 (52)	1280 (220)	70 (10)	293 (44)	BF and FF infants, Rotterdam, Netherlands
	32	2	5.2		4.2 (0.4)	19.8 (3.6)	373 (67)	1560 (280)	72 (9)	301 (37)	
	31	4	6.4		4.9 (0.4)	25.2 (3.4)	464 (74)	1940 (310)	73 (10)	304 (43)	
	22	8	8.2		6.2 (0.5)	26.2 (3.4)	657 (84)	2750 (350)	80 (10)	333 (40)	
	16	12	10.0		7.3 (0.6)	25.5 (3.5)	793 (91)	3320 (380)	79 (7)	332 (31)	
Jiang, 1998[30]	11BF	4	7.0 (0.9)	64.0 (1.6)	4.9 (0.5)	28.6 (4.0)	461 (129)	1930 (540)	66 (18)	275 (76)	BF and FF infants, Xinhui, China
	11FF	4	6.6 (0.8)	64.0 (2.1)	5.0 (0.8)	23.0 (5.0)	519 (161)	2170 (680)	78 (19)	326 (79)	
	9BF	6	7.2 (0.7)	66.7 (2.2)	5.3 (0.6)	26.4 (4.2)	424 (112)	1770 (470)	59 (18)	249 (77)	
	10FF	6	7.7 (0.7)	67.9 (1.9)	5.8 (0.4)	23.4 (6.8)	601 (121)	2520 (510)	78 (15)	325 (61)	
Stunkard, 1999[58]	23 BF & FF	3	6.0 (0.8)	61.1 (2.2)		24.1 (4.7)	425 (78)	1777 (326)	71	296	Lean mothers
	19 BF & FF	3	6.1 (0.6)	61.4 (1.9)		25.6 (3.7)	417 (84)	1743 (351)	68	286	Obese mothers, white TEE/SMR = 1.3
Salazar, 2000[59]	17 BF	1	4.6 (0.3)			17.7 (6.4)	288 (74)	1205 (312)	63	262	BF infants, Santiago, Chile
Butte, 2000[16]	39 BF	3	6.1 (0.6)	60.8 (1.7)	4.2 (0.5)	32.2 (6.6)	400 (80)	1674 (335)	65 (12)	272 (50)	BF and FF infants, Houston, TX
	28 FF	3	6.2 (0.7)	61.0 (1.8)	4.3 (0.4)	29.3 (5.6)	446 (93)	1866 (389)	73 (12)	305 (50)	TEE/SMR = 1.2–1.3

Table 1. *Continued*

Reference	*n*	Age (months)	Weight (kg)	Height (cm)	FFM (kg)	FM (%WT)	TEE (kcal day^{-1})	TEE (kJ day^{-1})	TEE (kcal kg^{-1} per day)	TEE (kJ kg^{-1} per day)	Comments
	37 BF	6	7.7 (0.7)	66.7 (1.8)	5.3 (0.5)	31.9 (5.4)	569 (112)	2381 (469)	73 (12)	305 (50)	
	23 FF	6	7.9 (0.8)	67.6 (1.7)	5.5 (0.7)	29.2 (4.1)	603 (91)	2523 (381)	78 (12)	326 (50)	
	36 BF	9	8.7 (0.9)	71.2 (1.7)	6.2 (0.6)	27.8 (4.2)	665 (103)	2782 (431)	77 (12)	322 (50)	
	20 FF	9	9.0 (0.8)	72.0 (2.1)	6.5 (0.8)	26.6 (5.0)	732 (101)	3063 (422)	82 (8)	343 (33)	
	36 BF	12	9.5 (1.0)	75.3 (1.7)	7.1 (0.8)	26.1 (4.6)	760 (134)	3180 (561)	79 (11)	330 (46)	
	21FF	12	9.9 (0.9)	76.1 (2.0)	7.1 (0.6)	27.5 (6.3)	797 (141)	3335 (590)	81 (13)	339 (54)	
Second year of life											
Davies, 1994[60]	23	18–30					1069 (254)	4472 (1062)			Cambridge, UK
Prentice, 1988[61]	15	12–24							83 (9)	347 (38)	Cambridge, UK
	12	24–36							81 (10)	339 (42)	
Fjeld, 1989[45]	22FF	16	7.0 (1.3)	70.9 (5.2)	6.0	14.0	629 (84)	2632 (351)	90 (12)	376 (50)	FF infants, Lima, Peru; Early recovery from malnutrition
	19FF	16.3	8.2 (1.2)	71.8 (4.9)	6.4	22.0	692 (82)	2895 (343)	84 (10)	351 (42)	Late recovery from malnutrition
Butte, 2000[16]	35 BF	18	11.0 (1.1)	82.0 (1.9)	8.2 (0.8)	24.4 (3.9)	858 (159)	3590 (665)	79 (12)	330 (50)	BF and FF infants
	24 FF	18	11.3 (1.1)	82.5 (2.4)	8.2 (0.9)	27.2 (6.0)	887 (148)	3711 (619)	79 (12)	330 (50)	TEE/SMR = 1.3-1.4
	32 BF	24	12.1 (1.2)	87.6 (2.7)	9.2 (1.0)	24.0 (3.6)	965 (144)	4038 (602)	80 (10)	335 (42)	
	20 FF	24	12.3 (1.2)	87.6 (2.7)	9.0 (1.3)	27.1 (4.2)	992 (176)	4150 (736)	81 (12)	339 (50)	

Abbreviations: TEE–total energy expenditure; SMR–sleeping metabolic rate; FFM–fat free mass; FM–fat mass; BF–breast-fed; FF–formula-fed; MF–mixed-fed.
[a]Mean (SD).

of TEE, with a slight advantage for weight. Since independent effects of age, sex and height were not demonstrated with weight entered, TEE for all infants was predicted simply from weight:

$$\text{TEE (kJ day}^{-1}) = 371\,\text{Weight (kg)} - 416, \quad \text{SEE} = 456$$

$$\text{TEE (kcal day}^{-1}) = 88.6\,\text{Weight (kg)} - 99.4, \quad \text{SEE} = 109$$

TEE for the breast-fed infants may be predicted from weight:

$$\text{TEE (kJ day}^{-1}) = 388\,\text{Weight (kg)} - 635, \quad \text{SEE} = 453$$

$$\text{TEE (kcal day}^{-1}) = 92.8\,\text{Weight (kg)} - 152, \quad \text{SEE} = 108$$

TEE for formula-fed infants may be predicted from weight:

$$\text{TEE (kJ day}^{-1}) = 346\,\text{Weight (kg)} - 122, \quad \text{SEE} = 463$$

$$\text{TEE (kcal day}^{-1}) = 82.6\,\text{Weight (kg)} - 29.0, \quad \text{SEE} = 110$$

In order to compare the regression equations derived from the individual TEE data with mean TEE values from other studies, linear regressions of mean TEE values on mean weights, weighed for sample sizes were performed, with and without Butte *et al.* data[16].

$$\text{TEE (kJ day}^{-1}) = 369\,\text{Weight (kg)} - 399$$

(including Butte *et al.*)

$$\text{TEE (kcal day}^{-1}) = 88.3\,\text{Weight (kg)} - 95.4$$

(including Butte *et al.*)

$$\text{TEE (kJ day}^{-1}) = 374\,\text{Weight (kg)} - 409$$

(excluding Butte *et al.*)

$$\text{TEE (kcal day}^{-1}) = 89.5\,\text{Weight (kg)} - 97.8$$

(excluding Butte *et al.*)

A limited number of TEE studies is available on infants living in developing countries who may be undernourished and exposed to harsher environmental conditions. Chilean infants studied at 1 month of age had TEE similar to well-nourished breast-fed infants in developed countries. A study was conducted in The Gambia where the infants were undernourished (65% <90th percentile weight for age) and stunted (36% <90th percentile weight for height). In another study of Mexican infants who had low weight-for-age and length-for-age Z-scores, TEE per kg body weight was significantly higher in the Mexican than American breast-fed infants[32]. Normalised for Fat free mass (FFM), the differences in TEE between cohorts diminished, but remained significant. Energy expenditure

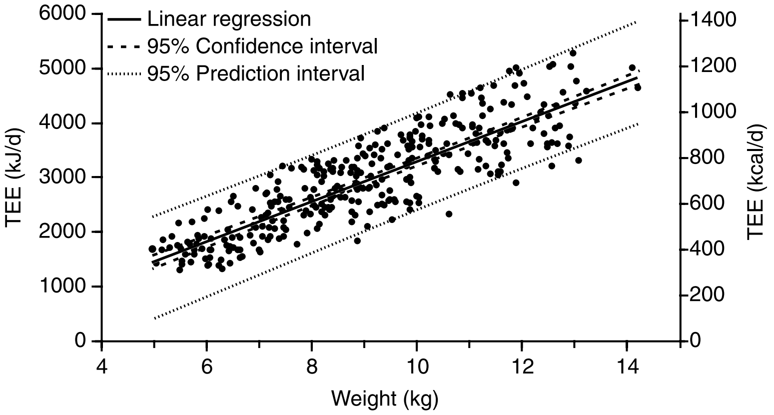

Fig. 1 Linear regression with 95% prediction and confidence intervals of total energy expenditure (TEE) by doubly labelled water method on weight, measured longitudinally on 76 healthy infants ($n = 40$ breast-fed and $n = 36$ formula-fed infants) throughout the first 2 years of life[16]

of malnourished Peruvian infants undergoing catch-up growth was elevated compared to well-nourished infants[33]. Their relatively high proportion of FFM accounted for the elevated TEE per unit body weight. A series of DLW studies was also conducted on Chinese breast-fed and formula-fed infants[30].

Mean TEE values (kJ day^{-1}, kcal day^{-1}) of infants living in developing versus developed countries are plotted as a function of mean weight in Fig. 2. The regression equations derived from mean TEE on mean weights, weighted for sample sizes, for infants living in developing countries were:

$$\text{TEE}\,(\text{kJ day}^{-1}) = 397\,\text{Weight}\,(\text{kg}) - 527$$

$$\text{TEE}\,(\text{kcal day}^{-1}) = 95.0\,\text{Weight}\,(\text{kg}) - 126$$

For a given weight, TEE tended to be higher in infants from developing than developed countries. Least squares regression, weighed by sample size, revealed a significant effect of weight and origin (developed or developing country) on TEE. Further studies are needed to confirm whether the increased TEE is due solely to differences in size and body composition or other mitigating factors.

Growth

Although the energy requirement for growth relative to maintenance is small, except for the first months of life, satisfactory growth is a sensitive indicator of whether energy needs are being met. The ECG may be divided into two components: the energy content of the tissues and the energy needed for synthetic processes. The ECG may be computed from the separate costs of protein and fat deposition, since the components of weight gain change dramatically through the first year of life. Much of our understanding of the ECG has been derived from preterm infants or children recovering from malnutrition (Table 2) [34]. Typically, the ECG in these studies ranges from 10 to 25 kJ g^{-1} (2.4–6.0 kcal g^{-1}), as the composition of the tissue synthesised varies. Based on the changes in body composition of Fomon's term infant reference[6], the total ECG fell from ~25 to 14 kJ g^{-1} (6–3.4 kcal g^{-1}) in the first year of life (Table 3).

Serial body composition measurements by TOBEC[35] and by a multi-component model based on TBW, TBK

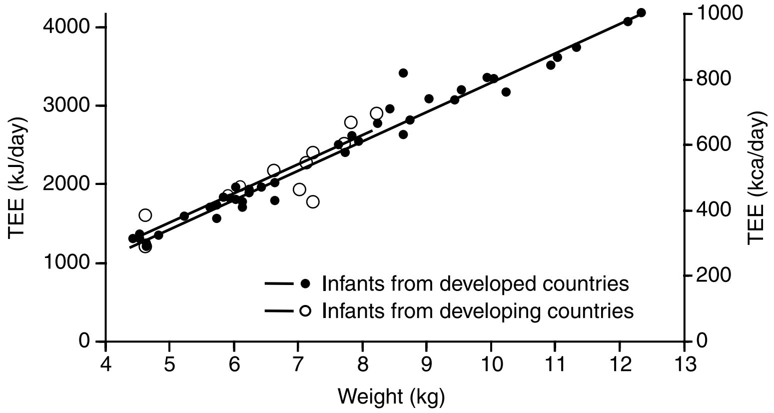

Fig. 2 Mean total energy expenditure (TEE) values of infants living in developing (○) vs. developed (•) countries are plotted as a function of mean weight

and BMC[16] can be used to estimate energy deposition from protein and fat gains. Energy deposition averaged 259, 556, 447, 224, and 127 kJ day^{-1} (62, 133, 107, 54, and 30 kcal day^{-1}) at 0–1, 1–2, 2–4, 4–8, and 8–12 months of age, respectively, in one study[35], and 490, 155, 90, 90, 75, and 65 kJ day^{-1} (117, 37, 22, 22, 18 and 16 kcal day^{-1}) at 3, 6, 9, 12, 18, and 24 months of age, respectively, in another[16]. Energy cost of tissue deposition decreased from ~26 kJ g^{-1} (~6.3 kcal g^{-1}) at 0–3 months to ~10 kJ g^{-1} (~2.3 kcal g^{-1}) at 9–12 months (Table 4). These values were applied to the weight velocities observed in the WHO pooled data set of breast-fed infants to estimate the rates of energy deposition[36].

Catch-up growth

Catch-up growth here refers to restoration of normal weight for height in a child who has been malnourished[37,38]. Astonishingly high rates of growth have been observed in wasted infants, up to 20 times normal rates. The average rate of growth of children who are only stunted is slower, about three times normal rates. Notwithstanding the need for energy and protein, all the essential nutrients required for tissue synthesis must be available for catch-up growth. The extent of the initial deficit, composition of gain, protein quality, and the efficiency of protein utilisation will affect the rates of catch-up growth.

The energy expenditure of infants recovering from malnutrition has been studied using indirect calorimetry and more recently using the doubly labelled water method. The TEE of Peruvian infants, 3–18 months of age, was 347 and 318 kJ kg^{-1} per day (83 and 76 kcal kg^{-1} per day), respectively, during the early and late phases of recovery from malnutrition[33]. Malnourished infants have been shown to have depressed metabolic rates[39] although the data are equivocal[40]. When infants are refed, their metabolic rates rise rapidly long before FFM is repleted, suggesting immediate restoration of normal cellular respiration.

The energy requirement for maintenance takes precedence over protein synthesis. Protein synthesis is a high energy-requiring process, and the supply of energy influences the rate of whole body protein metabolism. Over the range of energy intake, 251–1130 kJ kg^{-1} per day (60–270 kcal kg^{-1} per day), energy intake and the rate of protein turnover are positively correlated[41]. When energy intake is below maintenance needs, growth will cease. As the rate of weight gain increases, the protein requirement increases proportionately more than the requirement for energy[38] (Table 5).

Rapid weight gain during catch-up growth can restore normal body composition, if adequate protein is provided. Energy cost of tissue deposition (24

Table 2 Energy balance studies used to compute the energy cost of growth

				Weight gain			$E_{components}$		$E_{synthesis}$	
Reference	*n*	Age (months)	Weight (kg)	(g kg^{-1} per day)	E_{cg} (kJ g)	(kcal g^{-1})	(kJ g^{-1})	(kcal g^{-1})	(kJ g^{-1})	(kcal g^{-1})
Infants recovering from malnutrition										
Ashworth, 1969[20]	8	16.5 (8.1)[a]	5.1 (1.1)	10.0 (1.3)	40.2 (7.1)[b]	9.6 (1.7)	–		–	
		–	–	7.8 (0.9)	46.4 (4.6)	11.1 (1.1)	–		–	
Kerr *et al.*, 1973[62]	50	12.9	–	–	25.1[c]	6.0	19.7[d]	4.7	–	
Spady *et al.*, 1976[63]	11	12.2 (3.6)	5.2 (1.2)	8.4 (4.6)	18.4[c]	4.4	13.8 (6.3)[e]	3.3 (1.5)	4.6[f]	1.1
Jackson *et al.*, 1977[64]	5	14.8 (6.6)	6.8 (2.3)	–	–		25.9 (10.9)[e]	6.2 (2.6)	–	
Fjeld *et al.*, 1989[33]	11	15.2 (7.0)	6.1 (1.3)	5.7 (0.7)	–		21.3 (12.6)	5.1 (3.0)		
	11	13.5 (5.8)	5.7 (1.6)	11.8 (1.9)	–		24.3 (8.4)	5.8 (2.0)		
Fjeld *et al.*, 1989[45]	22	16.0 (6.5)	7.0 (1.3)	7.3 (3.8)	–		23.0 (10.0)	5.5 (2.4)	4.2 (2.5)	1.0 (0.6)
	19	16.3 (5.3)	8.2 (1.2)	7.6 (3.6)	–		23.4 (10.5)	5.6 (2.5)	4.2 (2.5)	1.0 (0.6)
Graham *et al.*, 1996[65]	14	9.5 (2.2)	5.4 (0.7)	–	31.8 (7.1)	7.6 (1.7)	–		–	
	15	11.2 (3.0)	6.0 (0.7)	–	–		–		–	
	15	8.8 (2.3)	5.1 (0.7)	–	–		–		–	
Preterm infants										
Brooke *et al.*, 1979[66]	15	0–2	1.9	13.7 (4.9)	23.8[c]	5.7	16.7 (2.5)[d]	4.0 (0.6)	7.1[f]	1.7
Chessex *et al.*, 1981[67]	13	0–1	1.2 (0.2)	13.9 (5.0)	–		–		2.8[g]	0.7
Gudinchet *et al.*, 1982[68]	15	0–2	1.4 (0.2)	11.2 (8.8)	–		–		2.2[g]	0.5
Reichman *et al.*, 1982[19]	13	0–1	1.3 (0.2)	16.8 (3.6)	20.5[h]	4.9	18.0[e]	4.3	2.8[g]	0.7
Whyte *et al.*, 1982[69]	15	0–2	1.9	13.7 (4.9)	18.4[c]	4.4	15.5[d]	3.7	–	
Sauer *et al.*, 1984[70]	14	0–2	1.6 (0.2)	18.7 (1.9)	–		11.7[e] (1.7)	2.8 (0.4)	1.1 (0.4)[i]	0.3 (0.1)
Freymond *et al.*, 1986[71]	9	0–1	–	16.6 (4)	–	4.0 (1.0)	10.9[e] (2.9)	2.6 (0.7)	–	

[a] Mean (SD).

[b] Total energy cost of growth (E_{cg}) = [Metabolizable energy intake (MEI) − basal metabolic rate (BMR)]/weight gain (WTG).

[c] E_{cg} = slope of regression of MEI on WTG.

[d] Energy deposition in tissues ($E_{components}$) = slope of regression of energy storage on WTG.

[e] $E_{components}$ = [MEI − total daily energy expenditure (TDEE)]/WTG.

[f] Energy cost of synthesis ($E_{synthesis}$) = E_{cg} − $E_{components}$.

[g] $E_{synthesis}$ = slope of regression of TDEE on WTG.

[h] E_{cg} = $E_{components}$ + $E_{synthesis}$.

[i] $E_{synthesis}$ = (metabolic rate − heat loss)/WTG.

Table 3 Energy cost of growth through infancy

Age (months)	Weight (kg)	Weight gain[a] (g day^{-1})	Fat deposition		Protein deposition		Energy cost of tissue deposition (kJ g^{-1})	Fat synthesis (kJ day^{-1})[d]	Protein synthesis (kJ day^{-1})	Total energy cost of growth		
			(g day^{-1})[b]	(kJ day^{-1})	(g day^{-1})[b]	(kJ day^{-1})[c]				(kJ day^{-1})	(kJ kg^{-1}	(kJ g^{-1})
Boys												
0–1	3.80	29	6	234	4	87	11	42	121	481	126	17
1–2	4.75	35	14	544	4	83	18	96	113	841	176	24
2–3	5.60	30	13	498	3	71	19	88	96	757	134	25
3–4	6.35	21	8	322	2	54	18	59	75	506	79	24
4–5	7.00	17	6	213	2	46	15	38	67	364	50	21
5–6	7.55	15	4	159	2	46	14	29	67	301	38	20
6–9	8.50	13	2	71	2	46	9	13	67	192	21	15
9–12	9.70	11	1	38	2	41	7	8	59	146	17	13
Girls												
0–1	3.60	26	6	218	3	79	11	38	109	439	121	17
1–2	4.35	29	13	494	3	66	19	88	92	741	172	26
2–3	5.05	24	10	389	3	62	19	67	84	607	121	25
3–4	5.70	19	7	285	2	50	18	50	67	452	79	24
4–5	6.35	16	6	230	2	46	17	42	63	377	59	23
5–6	6.95	15	5	188	2	46	15	33	63	331	46	22
6–9	7.97	11	2	67	2	41	10	13	59	180	21	16
9–12	9.05	10	1	46	2	41	9	8	54	151	17	15
Boys												
0–1	3.80	29	6	56	4	21	2.6	10	29	115	30	4.0
1–2	4.75	35	14	130	4	20	4.3	23	27	201	42	5.7
2–3	5.60	30	13	119	3	17	4.5	21	23	181	32	6.0
3–4	6.35	21	8	77	2	13	4.3	14	18	121	19	5.8
4–5	7.00	17	6	51	2	11	3.6	9	16	87	12	5.1
5–6	7.55	15	4	38	2	11	3.3	7	16	72	9	4.8
6–9	8.50	13	2	17	2	11	2.2	3	16	46	5	3.5
9–12	9.70	11	1	9	2	10	1.7	2	14	35	4	3.2
Girls												
0–1	3.60	26	6	52	3	19	2.7	9	26	105	29	4.0
1–2	4.35	29	13	118	3	16	4.6	21	22	177	41	6.1
2–3	5.05	24	10	93	3	15	4.5	16	20	145	29	6.0
3–4	5.70	19	7	68	2	12	4.2	12	16	108	19	5.7
4–5	6.35	16	6	55	2	11	4.1	10	15	90	14	5.6
5–6	6.95	15	5	45	2	11	3.7	8	15	79	11	5.3
6–9	7.97	11	2	16	2	10	2.4	3	14	43	5	3.9
9–12	9.05	10	1	11	2	10	2.1	2	13	36	4	3.6

[a] Rates of weight gain[6].

[b] Rates of fat and protein deposition[6].

[c] Energy equivalents for fat and protein deposition were taken as 9.25 kcal g^{-1} and 5.65 kcal g^{-1}, respectively.

[d] Energetic efficiencies of synthesizing protein and fat were taken to be 42% (1 kcal deposited/2.38 kcal used)and 85% (1 kcal deposited/1.17 kcal used), respectively[72].

Table 4 Weight gain and energy deposition of infant girls and boys

Age interval (months)	Protein gain (g day^{-1})^{a}	FM gain (g day^{-1})^{a}	Energy cost of tissue deposition (kJ g^{-1})^{a}	Energy cost of tissue deposition (kcal g^{-1})^{a}	Weight gain (g day^{-1})^{b}	Energy deposition (kJ day^{-1})^{b}	Energy deposition (kcal day^{-1})^{b}
Boys							
0–3	2.6	19.6	25	6.0	30	753	180
3–6	2.3	3.9	12	2.8	17	197	47
6–9	2.3	0.5	6	1.5	11	67	16
9–12	1.6	1.7	11	2.7	8	92	22
Girls							
0–3	2.2	19.7	26	6.3	28	732	175
3–6	1.9	5.8	15	3.7	16	251	60
6–9	2	0.8	8	1.8	10	75	18
9–12	1.8	1.1	10	2.3	6	58	14

[a] Energy cost of tissue deposition[73].
[b] Weight gain[36].

and 21 kJ g^{-1}) (5.8 and 5.1 kcal g^{-1}) during rapid weight gain (79 g day^{-1}) did not differ statistically from that during moderate weight gain (41 g day^{-1})[42]. In the early phase of recovery, the composition of weight gained was 20% protein, 40% fat and 40% water in the moderate gain group, and 14% protein, 43% fat and 43% water in the rapid gain group. In the late phase of recovery, the composition of gain did not differ statistically from the early phase. The observation that the rate of weight gain did not influence the composition of gain differs from previous reports[43,44], in which hypercaloric feedings and accelerated weight gain led to increased fat deposition. However, it is possible that protein at 5–6.4% of energy was limiting in the diet. Fjeld *et al.*[42] fed 544 kJ kg^{-1} per day (130 kcal kg^{-1} per day) and 3–4 and 2–3 g kg^{-1} per day protein in the moderate gain group, and 711 kJ kg^{-1} per day (170 kcal kg^{-1} per day) and 4–5 g kg^{-1} per day protein in the rapid gain group, which was equivalent to 8–11% energy as protein.

A model to predict metabolizable energy (ME) requirements of children recovering from malnutrition was developed in 22 children (16 ± 6 months of age) based on TEE and body composition measurements[45].

$$\text{ME (kJ kg}^{-1}\text{ per day)} = 410 \times \text{FFM/WT} + \text{A}(46.4\,\text{B} + 9.2\,\text{C})$$

$$\text{ME (kcal kg}^{-1}\text{ per day)} = 98 \times \text{FFM/WT} + \text{A}(11.1\,\text{B} + 2.2\,\text{C})$$

where A is the rate of weight gain (g kg^{-1} per day); B is the fractional percentage of fat gain and C is the fractional percentage of FFM gain.

WHO recommends two formulas for severely malnourished children, after clinical stabilisation[46]. The F-75 formulation is used during the initial phase of treatment, and the F-100 is used during the rehabilitation phase. The constituents of both include dried skimmed milk, sugar, cereal flour, vegetable oil, mineral mix, vitamin mix and water. During the initial phase, the child should be given at least 335 kJ kg^{-1} per day (80 kcal kg^{-1} per day), but not more than 418 kJ kg^{-1} per day (100 kcal kg^{-1} per day) of F-75 formula. The F-75 formula has 315 kJ (75 kcal)/100 mL, 0.9 g protein/100 mL, 5% of energy from protein, and 32% from fat. When the child's appetite improves and clinical condition permits, he/she is ready for advancement to the F-100 formulation. The F-100 formula has 420 kJ (100 kcal)/100 mL, 2.9 g protein/100 mL, 12% of energy from protein, and 53% from fat. The frequency and modality of feeding are critical, and outlined in the WHO publication[46].

Table 5 Macronutrient requirements at different rates of weight gain

Rate of weight gain (g kg^{-1} per day)	kJ kg^{-1} per day	Energy (kcal kg^{-1} per day)^{a}	Protein (g kg^{-1} per day)^{b}	Protein (g protein/100 kcal)^{b}	Protein:energy ratio (%)
None	356	85	0.62	0.73	2.9
1	376	90	0.83	0.92	3.7
2	393	94	1.04	1.11	4.4
5	452	108	1.67	1.55	6.2
10	544	130	2.72	2.09	8.4
20	728	174	4.82	2.77	11.1

[a] Assumes intake for zero energy balance is 85.5 kcal kg^{-1} per day, and cost of weight gain is 4.4 kcal g^{-1}, which indicates that the composition of the tissue deposited is 73.5% lean and 26.5% fat.
[b] Assumes intake for zero N balance is 100 mg N/kg per day, protein content of weight gain is 14.7%, and efficiency of dietary protein utilisation for tissue deposition is 70%.
Modified from Ashworth and Millward, 1986[38].

Influence of infections on energy requirements

Infectious diseases heighten the demand for energy because of increased protein turnover, production of acute phase proteins and cytokines, tissue repair, proliferation of phagocytes and lymphocytes, and poor lipid utilisation with increased gluconeogenesis[47]. Intestinal parasites apparently have little or no effect on protein and energy requirements unless the infestation is extensive or causes diarrhoea. Anorexic effects, along with pyrexia, catabolic losses, and malabsorption, result in weight loss during infectious episodes.

The effect of infection on energy expenditure will depend on the type, severity and duration of the infection, as well as the nutritional status of the host[47]. The metabolic rate increases in response to fever by approximately 13% for each 1°C rise in body; however, the response may be blunted in malnourished infants and may be compensated by behavioural adaptations. Undernourished Kenyan toddlers with measles showed no change in RMR[48]. Eccles *et al.*[49] showed in Gambian infants that malaria suppressed SMR, accounting for the effect of fever. The lethargy, increased sleep, and bed rest associated with illness most likely outweigh any physiological increases in energy expenditure[50].

Increased energy needs for catch-up growth following an infectious episode may not be met by the traditional diet[37]. High energy-density formulations may be needed during the short anabolic periods following episodes of weight loss to restore growth.

Total energy requirement of infants

Energy requirements of infants were derived from TEE measured by the DLW method and energy deposition based on rates of protein and fat gains[16]. Energy requirements are presented for all infants (Table 6), breast-fed infants (Table 7) and for formula-fed infants (Table 8). Total energy requirements naturally increase as the infants grow, and are higher in boys than girls due to differences in weight (Fig. 3). In contrast to the 1985 FAO/WHO/UNU recommendations[1], energy requirements adjusted for body weight do not display a curvilinear pattern (Fig. 4). Instead, energy requirements decrease from 473 kJ kg^{-1} per day for boys and 447 kJ kg^{-1} per day for girls at 1 month of age to 337 kJ kg^{-1} per day for boys and 341 kJ kg^{-1} per day for girls at 6 months, and thereafter tend to plateau. Energy deposition as a percentage of total energy requirement decreases from 40% at 1 month to 3% at 12 months of age.

Recommendations

As outlined in the 1985 FAO/WHO/UNU publication[1], energy requirements during infancy may be represented by

Table 6 Energy requirements for all infants 0–12 months of age

Age (months)	Weight (kg)[a]	Weight velocity (g day^{-1})[b]	Total energy expenditure (kJ day^{-1})	Total energy expenditure (kcal day^{-1})	Energy deposition (kJ day^{-1})	Energy deposition (kcal day^{-1})	Energy requirement (kJ day^{-1})	Energy requirement (kcal day^{-1})	Energy requirement (kJ kg^{-1} per day)	Energy requirement (kcal kg^{-1} per day)
Boys										
1	4.58	35.2	1282	306	884	211	2166	518	473	113
2	5.5	30.4	1623	388	764	183	2387	570	434	104
3	6.28	23.2	1912	457	582	139	2494	596	397	95
4	6.94	19.1	2157	515	224	53	2380	569	343	82
5	7.48	16.1	2357	563	189	45	2546	608	340	81
6	7.93	12.8	2524	603	150	36	2674	639	337	81
7	8.3	11.0	2661	636	69	17	2730	653	329	79
8	8.62	10.4	2780	664	65	16	2845	680	330	79
9	8.89	9.0	2880	688	57	14	2936	702	330	79
10	9.13	7.9	2969	710	89	21	3058	731	335	80
11	9.37	7.7	3058	731	87	21	3145	752	336	80
12	9.62	8.2	3150	753	93	22	3243	775	337	81
Girls										
1	4.35	28.3	1197	286	746	178	1942	464	447	107
2	5.14	25.5	1490	356	672	161	2162	517	421	101
3	5.82	21.2	1742	416	559	134	2301	550	395	94
4	6.41	18.4	1960	469	285	68	2245	537	350	84
5	6.92	15.5	2149	514	239	57	2389	571	345	83
6	7.35	12.8	2309	552	199	47	2507	599	341	82
7	7.71	11.0	2442	584	83	20	2525	604	328	78
8	8.03	9.2	2561	612	69	17	2630	629	328	78
9	8.31	8.4	2665	637	63	15	2728	652	328	78
10	8.55	7.7	2754	658	74	18	2828	676	331	79
11	8.78	6.6	2839	679	63	15	2902	694	331	79
12	9	6.3	2920	698	60	14	2981	712	331	79

[a] 50th percentile weight-for-age of the WHO pooled breast-fed data set[36].
[b] 50th percentile weight increment of the WHO pooled breast-fed data set[36].

Table 7 Energy requirements for breast-fed infants 0–12 months of age

Age (months)	Weight (kg)[a]	Weight velocity (g day^{-1})[b]	Total energy expenditure (kJ day^{-1})	Total energy expenditure (kcal day^{-1})	Energy deposition (kJ day^{-1})	Energy deposition (kcal day^{-1})	Energy requirement (kJ day^{-1})	Energy requirement (kcal day^{-1})	Energy requirement (kJ kg^{-1} per day)	Energy requirement (kcal kg^{-1} per day)
Boys										
1	4.58	35.2	1144	273	884	211	2027	485	443	106
2	5.5	30.4	1501	359	764	183	2265	541	412	98
3	6.28	23.2	1804	431	582	139	2386	570	380	91
4	6.94	19.1	2060	492	224	53	2283	546	329	79
5	7.48	16.1	2270	542	189	45	2458	588	329	79
6	7.93	12.8	2444	584	150	36	2595	620	327	78
7	8.3	11.0	2588	619	69	17	2657	635	320	77
8	8.62	10.4	2712	648	65	16	2777	664	322	77
9	8.89	9.0	2817	673	57	14	2874	687	323	77
10	9.13	7.9	2910	696	89	21	2999	717	329	79
11	9.37	7.7	3003	718	87	21	3091	739	330	79
12	9.62	8.2	3100	741	93	22	3193	763	332	79
Girls										
1	4.35	28.3	1054	252	746	178	1800	430	414	99
2	5.14	25.5	1361	325	672	161	2033	486	396	95
3	5.82	21.2	1625	388	559	134	2184	522	375	90
4	6.41	18.4	1854	443	285	68	2139	511	334	80
5	6.92	15.5	2052	490	239	57	2291	548	331	79
6	7.35	12.8	2219	530	199	47	2418	578	329	79
7	7.71	11.0	2359	564	83	20	2442	584	317	76
8	8.03	9.2	2483	593	69	17	2553	610	318	76
9	8.31	8.4	2592	619	63	15	2655	635	319	76
10	8.55	7.7	2685	642	74	18	2759	660	323	77
11	8.78	6.6	2774	663	63	15	2838	678	323	77
12	9	6.3	2860	684	60	14	2920	698	324	78

[a] 50th percentile weight for age of the WHO pooled breast-fed data set[36].
[b] 50th percentile weight increment of the WHO pooled breast-fed data set[36].

Table 8 Energy requirements for formula-fed infants 0–12 months of age

Age (months)	Weight (kg)[a]	Weight velocity (g day^{-1})[b]	Total energy expenditure (kJ day^{-1})	Total energy expenditure (kcal day^{-1})	Energy deposition (kJ day^{-1})	Energy deposition (kcal day^{-1})	Energy requirement (kJ day^{-1})	Energy requirement (kcal day^{-1})	Energy requirement (kJ kg^{-1} per day)	Energy requirement (kcal kg^{-1} per day)
Boys										
1	4.58	35.2	1462	349	884	211	2345	560	512	122
2	5.5	30.4	1779	425	764	183	2543	608	462	111
3	6.28	23.2	2049	490	582	139	2631	629	419	100
4	6.94	19.1	2277	544	224	53	2501	598	360	86
5	7.48	16.1	2464	589	189	45	2653	634	355	85
6	7.93	12.8	2619	626	150	36	2770	662	349	83
7	8.3	11.0	2747	657	69	17	2816	673	339	81
8	8.62	10.4	2858	683	65	16	2923	699	339	81
9	8.89	9.0	2951	705	57	14	3008	719	338	81
10	9.13	7.9	3034	725	89	21	3123	746	342	82
11	9.37	7.7	3117	745	87	21	3204	766	342	82
12	9.62	8.2	3203	766	93	22	3296	788	343	82
Girls										
1	4.35	28.3	1382	330	746	178	2128	509	489	117
2	5.14	25.5	1655	396	672	161	2327	556	453	108
3	5.82	21.2	1890	452	559	134	2449	585	421	101
4	6.41	18.4	2094	500	285	68	2379	569	371	89
5	6.92	15.5	2270	543	239	57	2510	600	363	87
6	7.35	12.8	2419	578	199	47	2617	626	356	85
7	7.71	11.0	2543	608	83	20	2626	628	341	81
8	8.03	9.2	2654	634	69	17	2723	651	339	81
9	8.31	8.4	2751	657	63	15	2814	673	339	81
10	8.55	7.7	2834	677	74	18	2908	695	340	81
11	8.78	6.6	2913	696	63	15	2976	711	339	81
12	9	6.3	2989	714	60	14	3049	729	339	81

[a] 50th percentile weight for age of the WHO pooled breast-fed data set[36].
[b] 50th percentile weight increment of the WHO pooled breast-fed data set[36].

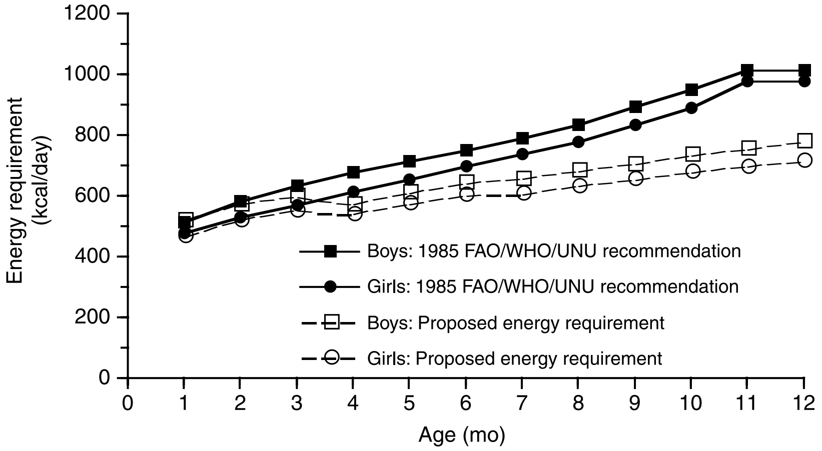

Fig. 3 The 1985 FAO/WHO/UNU recommendations[1] for energy intake of infants (kcal day^{-1}) vs. the proposed energy requirements for boys and girls

the average requirements of individual infants and should be determined from estimates of energy expenditure. The database of TEE determined by DLW is now sufficiently large to estimate average TEE during infancy. Body composition measurements are available to estimate energy deposition. Therefore, recommendations for energy intake of infants should be based upon measurements of TEE and energy deposition. The 1985 FAO/WHO/UNU recommendations are 10–32% higher than the total energy requirements estimated here within and should be revised.

Areas for further research

1. The number of available DLW studies on infants from developing countries is limited and should be expanded in normal-weight and IUGR infants. Further studies are needed to confirm whether the increased TEE observed in some settings is due solely to differences in size and body composition or other mitigating factors.
2. The DLW method provides a means of determining the amount of energy expended in physical activity. Physical activity levels consistent with normal health and development of infants should be described qualitatively and ethnographically across cultures.
3. Physiological adjustments in physical activity and growth in response to undernutrition should be investigated with more recent technologies.
4. The effect of the quality of dietary protein, carbohydrate and fat upon rates of weight gain, particularly during recovery from malnutrition, should be explored.
5. Nutrient needs for rehabilitation of stunted children are poorly understood. Special nutrient requirements for catch-up linear growth require further research.
6. The number of studies on the effect of infection on energy requirements of infants is limited, and should be expanded to cover a broad range of infectious agents of varying severity and duration.
7. Factors affecting the dietary intake that is necessary to satisfy energy requirements should be explored,

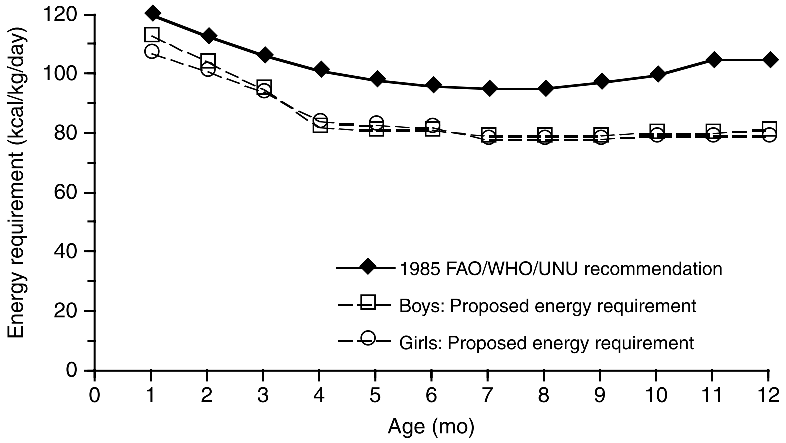

Fig. 4 The 1985 FAO/WHO/UNU recommendations[1] for energy intake of infants (kcal kg^{-1} per day) vs. the proposed energy requirements for boys and girls

including diet digestibility, viscosity, and energy and nutrient density.

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