



3. ENERGY REQUIREMENTS OF INFANTS FROM BIRTH TO 12 MONTHS

The principle of calculating energy requirements from total energy expenditure (TEE) plus the energy needs for growth applies to infants and children of all ages. However, the previous FAO/WHO/UNU expert consultation (WHO, 1985) estimated the energy requirements of infants from the observed intakes of healthy children growing normally, largely owing to the lack of sufficient information on total energy expenditure. For the last report, data on measurements of infants and children were compiled from studies of infants in Canada, Sweden, the United Kingdom and the United States (Whitehead, Paul and Cole, 1981). Results from developing countries were not included in the analysis "to ensure that the intakes represented those of groups of children who, on the average, were growing along the fiftieth percentile of the WHO reference standard". An additional 5 percent was added to compensate for a possible methodological bias in the calculation of energy intakes.

Scientific information generated in the intervening years has allowed the present consultation to base its estimates and recommendations for infants on energy expenditure plus the energy needs for growth. This assumes that the energy intake of infants is self-regulated and matches energy needs (Fomon, 1974; Dewey and Lönnerdal, 1986). In keeping with the principles followed by preceding expert groups, it was decided to base the analyses, conclusions and recommendations on results of studies carried out on healthy, well-nourished, non-stunted infants born at full term with adequate birth weight, and growing along the trajectory of the WHO reference standards (WHO, 1983). This permits the prescription of dietary recommendations consistent with the optimal growth of healthy, well-nourished infant populations. Special considerations must be made for groups with particular needs, such as undernourished infants and those with low weight or size at birth.

3.1 Measurement of total energy expenditure

The use of the doubly labelled water (DLW) ($^2\text{H}_2^{18}\text{O}$) technique to calculate total production of carbon dioxide (CO_2) over several days and, from this, total energy expenditure was originally developed for use in small mammals (Lifson, Gordon and McClintock, 1955), and its application was later validated in humans (Schoeller and van Santen, 1982; Klein *et al.*, 1984; Coward *et al.*, 1984). Although questions have been raised about the appropriateness of the assumptions used for the calculation of TEE, DLW is currently considered the most accurate technique for measuring TEE in free-living individuals. TEE measured by this method includes basal metabolism, the metabolic response to food, thermoregulatory needs, physical activity costs, and the energy cost to synthesize growing tissues. Consequently, energy requirements are calculated as the sum of TEE plus the energy deposited as protein and fat in growing tissues and organs.

This consultation examined an analysis of 13 studies with DLW performed on a total of 417 healthy, well-nourished, non-stunted infants of from 0 to 12 months of age (Butte, 2001). Eleven investigations were carried out in the United Kingdom (Lucas *et al.*, 1987; Roberts *et al.*, 1988; Davies, Ewing and Lucas, 1989; Wells and Davies, 1995; Wells, Cole and Davies, 1996; Davies *et al.*, 1997), the United States (Butte *et al.*, 1990; Stunkard *et al.*, 1999; Butte *et al.*, 2000b) and the Netherlands (de Bruin *et al.*, 1998), one in Chile (Salazar *et al.*, 2000) and one in China (Jiang *et al.*, 1998). Several studies conducted repeated measurements of TEE at intervals of two to three months, increasing the number of TEE data points to 854. One such study showed that the coefficient of variation among individuals was fairly uniform from three to 24 months of age, ranging from 15 to 21 percent for TEE/day (average: 18 percent), and from 13 to 17 percent for TEE/kg/day (average: 15 percent) (Butte *et al.*, 2000b). The average inter-individual variation was similar to that observed among older children (19 percent for TEE/day, and 17 percent for TEE/kg/day; see section 4.1).

3.2 Equations to predict energy expenditure

Longitudinal measurements of TEE with DLW at three-month intervals for the first two years of life on 76 healthy infants (40 breastfed and 36 formula-fed) showed that there is a good linear relationship between TEE and body weight (Butte *et al.*, 2000b). TEE was significantly affected by age, gender, weight and length. Age, weight and

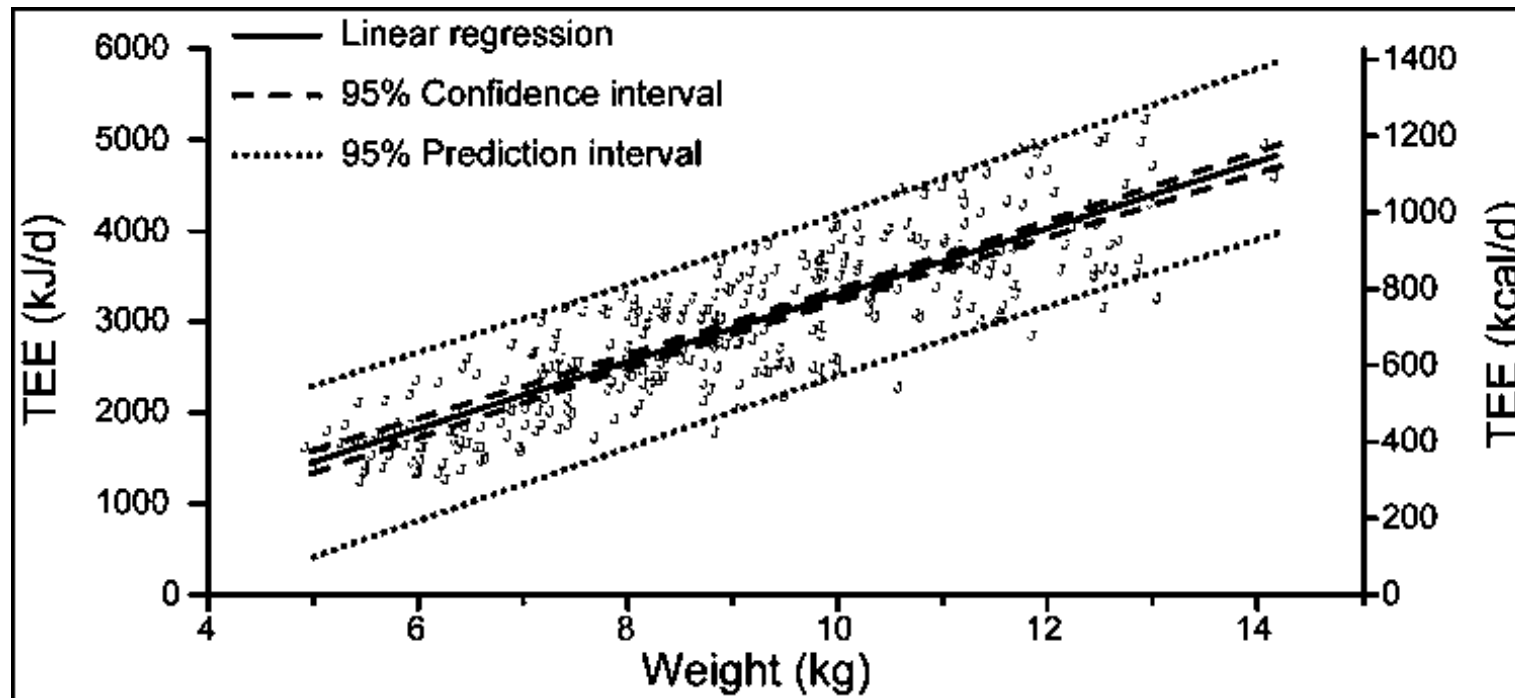
height were all good predictors of TEE, with a slight advantage for weight. Because the three parameters were highly correlated ($r = 0.91 - 0.96$), and there were no independent effects of age, gender and length when weight was used as the predictor, the latter was used to develop the following equation (Butte, 2001), which is graphically displayed in Figure 3.1.

TEE (MJ/day) = $- 0.416 + 0.371 \text{ kg}$; $n = 320$, $r = 0.85$, $\text{see}^* = 0.456 \text{ MJ/day}$ (109 kcal/day)

TEE (kcal/day) = $- 99.4 + 88.6 \text{ kg}$

FIGURE 3.1

Linear relationship and 95 percent confidence and prediction intervals of equation to predict TEE from body weight in healthy infants, one to 24 months old



TEE (MJ/d) = $- 0.416 + 0.371 \text{ kg}$; $n = 320$, $r = 0.85$, $\text{see}^* = 0.456 \text{ MJ/d}$ (109 kcal/d).

TEE (kcal/d) = $- 99.4 + 88.6 \text{ kg}$.

Source: Butte, 2001.

*see = standard error of estimate

The relationship between TEE and weight in the 13 studies mentioned in Section 3.1 was explored using the mean values for TEE and body weight. Some studies included longitudinal or cross-sectional data at various ages throughout infancy, or from groups of either breastfed or formula-fed infants. A total of 40 sets of TEE and body weight values, weighted for sample size, gave the following linear regression equation, which does not differ significantly from that shown above:

TEE (MJ/day) = $- 0.399 + 0.369 \text{ kg}$; $n = 40$, $r = 0.99$, $\text{see} = 0.527 \text{ MJ/day}$ (126 kcal/day)

TEE (kcal/day) = $- 95.4 + 88.3 \text{ kg}$

As the equation was derived from the mean values of each study, the regression coefficient and standard error of estimate (see) do not reflect individual variation.

3.2.1 Breastfed and formula-fed infants

Four studies with breastfed and formula-fed infants showed that the formula-fed infants had higher TEE during the first year of life (Butte *et al.*, 1990; Butte *et al.*, 2000b; Jiang *et al.*, 1998; Davies *et al.*, 1990). Compared with their breastfed counterparts, formula-fed infants had on average 12, 7, 6 and 3 percent higher TEE at three, six, nine and 12 months of age, respectively. At 18 and 24 months, there was no difference between infants who still received breastmilk and those who did not (Butte, 2001). The equations to predict TEE from body weight are as follows:

Breastfed:

TEE (MJ/day) = - 0.635 + 0.388 kg; n = 195, r = 0.87, see = 0.453 MJ/day (108 kcal/day)

TEE (kcal/day) = - 152.0 + 92.8 kg

Formula-fed:

TEE (MJ/day) = - 0.122 + 0.346 kg; n = 125, r = 0.85, see = 0.463 MJ/day (110 kcal/day)

TEE (kcal/day) = - 29.0 + 82.6 kg

3.3 Energy needs for growth

Growth is a sensitive indicator of whether an infant's energy requirements are satisfied. Energy demands for growth constitute about 35 percent of the total energy requirement during the first three months of life (40 percent in the first month), this proportion is halved in the next three months (i.e. to about 17.5 percent), and further reduced to one-third of that during the ensuing six months (i.e. to less than 6 percent) and to only 3 percent at 12 months. Energy for growth falls to less than 2 percent of daily requirements in the second year, remains between 1 and 2 percent until mid-adolescence, and gradually disappears by 20 years of age.

Energy needs for growth have two components: 1) the energy used to synthesize growing tissues, which is part of the total energy expenditure measured with DLW; and 2) the energy deposited in those tissues, basically as fat and protein, because carbohydrate content is insignificant. Hence, energy requirements in infancy can be calculated by adding the energy deposited in growing tissues to TEE.

Much previous knowledge on the energy cost of growth was based on studies in pre-term infants or in children recovering from malnutrition, and used energy balance and the two-component body composition techniques (WHO, 1985; Butte, Wong and Garza, 1989). Methodological advances have allowed a better assessment of body composition changes during infancy through serial measurements of total body electrical conductivity (de Bruin *et al.*, 1998), or with a multi-component body composition model based on measurements of total body water, total body potassium and bone mineral content (Butte *et al.*, 2000a). This permits calculation of the gains in protein and fat, as well as of the corresponding energy deposition assuming that the energy equivalents of protein and fat are 23.6 and 38.7 kJ/g (5.65 and 9.25 kcal/g), respectively. As Table 3.1 shows, energy accrued per gram of weight gain decreased from approximately 26 kJ (6.3 kcal) in the first three months of life to about 10 kJ (2.3 kcal) at nine to 12 months.

TABLE 3.1
Protein, fat and energy deposition during growth in the first year of life

Age months	Protein gain g/d	Fat mass gain g/d	Weight gain g/d	Energy accrued in normal growth*	
				kJ/g	kcal/g
Boys					
0-3	2.6	19.6	32.7	25.1	6.0
3-6	2.3	3.9	17.7	11.6	2.8
6-9	2.3	0.5	11.8	6.2	1.5

9-12	1.6	1.7	9.1	11.4	2.7
Girls					
0-3	2.2	19.7	31.1	26.2	6.3
3-6	1.9	5.8	17.3	15.6	3.7
6-9	2.0	0.8	10.6	7.4	1.8
9-12	1.8	1.1	8.7	9.8	2.3

* Energy equivalents: 1 g protein = 23.6 kJ (5.65 kcal); 1 g fat = 38.7 kJ (9.25 kcal).

Source: Butte *et al.*, 2000a.

TABLE 3.2
Energy requirements of infants during the first year of life*

Age months	Weight kg	Weight gain g/d	Total energy expenditure ^a		Energy deposition ^b		Daily energy requirement ^c			
			MJ/d	kcal/d	MJ/d	kcal/d	MJ/d	kcal/d	kJ/kg/d	kcal/kg/d
Boys										
0-1	4.58	35.2	1.282	306	0.884	211	2.166	518	473	113
1-2	5.50	30.4	1.623	388	0.764	183	2.387	570	434	104
2-3	6.28	23.2	1.912	457	0.582	139	2.494	596	397	95
3-4	6.94	19.1	2.157	515	0.224	53	2.380	569	343	82
4-5	7.48	16.1	2.357	563	0.189	45	2.546	608	340	81
5-6	7.93	12.8	2.524	603	0.150	36	2.674	639	337	81
6-7	8.30	11.0	2.661	636	0.069	17	2.730	653	329	79
7-8	8.62	10.4	2.780	664	0.065	16	2.845	680	330	79
8-9	8.89	9.0	2.880	688	0.057	14	2.936	702	330	79
9-10	9.13	7.9	2.969	710	0.089	21	3.058	731	335	80
10-11	9.37	7.7	3.058	731	0.087	21	3.145	752	336	80
11-12	9.62	8.2	3.150	753	0.093	22	3.243	775	337	81
Girls										
0-1	4.35	28.3	1.197	286	0.746	178	1.942	464	447	107
1-2	5.14	25.5	1.490	356	0.672	161	2.162	517	421	101
2-3	5.82	21.2	1.742	416	0.559	134	2.301	550	395	94
3-4	6.41	18.4	1.960	469	0.285	68	2.245	537	350	84
4-5	6.92	15.5	2.149	514	0.239	57	2.389	571	345	83
5-6	7.35	12.8	2.309	552	0.199	47	2.507	599	341	82
6-7	7.71	11.0	2.442	584	0.083	20	2.525	604	328	78
7-8	8.03	9.2	2.561	612	0.069	17	2.630	629	328	78
8-9	8.31	8.4	2.665	637	0.063	15	2.728	652	328	78

9-10	8.55	7.7	2.754	658	0.074	18	2.828	676	331	79
10-11	8.78	6.6	2.839	679	0.063	15	2.902	694	331	79
11-12	9.00	6.3	2.920	698	0.060	14	2.981	712	331	79

* Calculated from linear regression analysis of total energy expenditure on weight, plus allowance for energy deposition in tissues during growth.

^a TEE (MJ/d) = - 0.416 + 0.371 kg (section 3.2).

^b Weight gain × energy accrued in normal growth (Table 3.1).

^c Requirement = total energy expenditure + energy deposition.

Sources: Butte, 2001. Weight and weight gain data from WHO, 1994.

3.4 Calculation of energy requirements

Table 3.2 shows the average energy requirements of infants from one to 12 months of age, combining the needs of breastfed and formula-fed infants. TEE was calculated with the predictive linear equations described in section 3.2 and the median weight for age of the WHO pooled breastfed data set (WHO, 1994). The rate of median weight gain at monthly intervals was calculated from the same source. Energy deposited in growing tissues was estimated by multiplying the monthly weight gain by the mean energy accrued in each three-month period (Table 3.1). The sum of TEE and energy deposition is the mean daily energy requirement (in MJ or kcal). It is calculated as energy units per kilogram of body weight, dividing the daily requirement by the median weight at each month of age.

Breastmilk is the best food for infants, and exclusive breastfeeding is strongly recommended during the first six months of life, followed by a combination of breastmilk and complementary foods throughout infancy. As TEE is lower among breastfed than formula-fed infants during the first year of life, the energy requirements of breastfed infants are also lower. This is illustrated in Table 3.3, in which requirements are calculated for breastfed and formula-fed infants with the same body weights using the predictive equations described in section 3.2.1. For the purpose of simplicity, the values have been rounded off to the closest 5 kJ/kg/day, or 1 kcal/kg/day. These figures are consistent with the fact that a healthy woman can produce enough milk to provide the energy required by a healthy, exclusively breastfed infant of up to six months of age.

TABLE 3.3
Energy requirements of breastfed, formula-fed and all infants*

Age Months	Breastfed ^a			Formula-fed ^b			All (breast- and formula-fed) ^c		
	Boys	Girls	Mean	Boys	Girls	Mean	Boys	Girls	Mean
kJ/kg/d									
1	445	415	430	510	490	500	475	445	460
2	410	395	405	460	455	460	435	420	430
3	380	375	380	420	420	420	395	395	395
4	330	335	330	360	370	365	345	350	345
5	330	330	330	355	365	360	340	345	345
6	325	330	330	350	355	355	335	340	340
7	320	315	320	340	340	340	330	330	330
8	320	320	320	340	340	340	330	330	330
9	325	320	320	340	340	340	330	330	330
10	330	325	325	340	340	340	335	330	335

11	330	325	325	340	340	340	335	330	335
12	330	325	330	345	340	340	335	330	335
kcal/kg/d									
1	106	99	102	122	117	120	113	107	110
2	98	95	97	110	108	109	104	101	102
3	91	90	90	100	101	100	95	94	95
4	79	80	79	86	89	87	82	84	83
5	79	79	79	85	87	86	81	82	82
6	78	79	78	83	85	84	81	81	81
7	76	76	76	81	81	81	79	78	79
8	77	76	76	81	81	81	79	78	79
9	77	76	77	81	81	81	79	78	79
10	79	77	78	82	81	81	80	79	80
11	79	77	78	82	81	81	80	79	80
12	79	77	78	82	81	81	81	79	80

* Numbers rounded to the closest 5 kJ/kg/d, and 1 kcal/kg/d, using the mean body weight and energy deposition in Table 3.1 and the following predictive equations for TEE:

^a TEE (MJ/kg/d) = (- 0.635 + 0.388 weight)/weight.

^b TEE (MJ/kg/d) = (- 0.122 + 0.346 weight)/weight.

^c TEE (MJ/kg/d) = (- 0.416 + 0.371 weight)/weight.

3.4.1 Comparison with previous requirements

Compared with the values in the 1985 FAO/WHO/UNU report, energy requirements proposed by this consultation are about 12 percent lower in the first three months of life, 17 percent lower from three to nine months, and 20 percent lower from nine to 12 months (Table 3.4 and Figure 3.2). The requirements for breastfed infants are 17, 20 and 22 percent lower than the 1985 estimates at ages 0 to three, three to nine and nine to 12 months, respectively. That the 1985 consultation overestimated requirements of this group had already been suggested from an analysis of 3 573 data points of energy intakes of well-nourished infants recorded after 1980 (Butte, 1996).

TABLE 3.4

Comparison of present estimates of energy requirements of infants with those calculated in the previous (1985) FAO/WHO/UNU report

Age months	Present estimates kJ/kg/d		1985 estimates kJ/kg/d	% difference from 1985	
	All infants	Breastfed		All infants	Breastfed
0-1	460	430	519	-11	-17
1-2	430	405	485	-11	-16
2-3	395	380	456	-13	-17
3-4	345	330	431	-20	-23

4-5	345	330	414	-17	-20
5-6	340	330	404	-16	-18
6-7	330	320	397	-17	-19
7-8	330	320	395	-16	-19
8-9	330	320	397	-17	-19
9-10	335	325	414	-19	-21
10-11	335	325	418	-20	-22
11-12	335	330	437	-23	-24

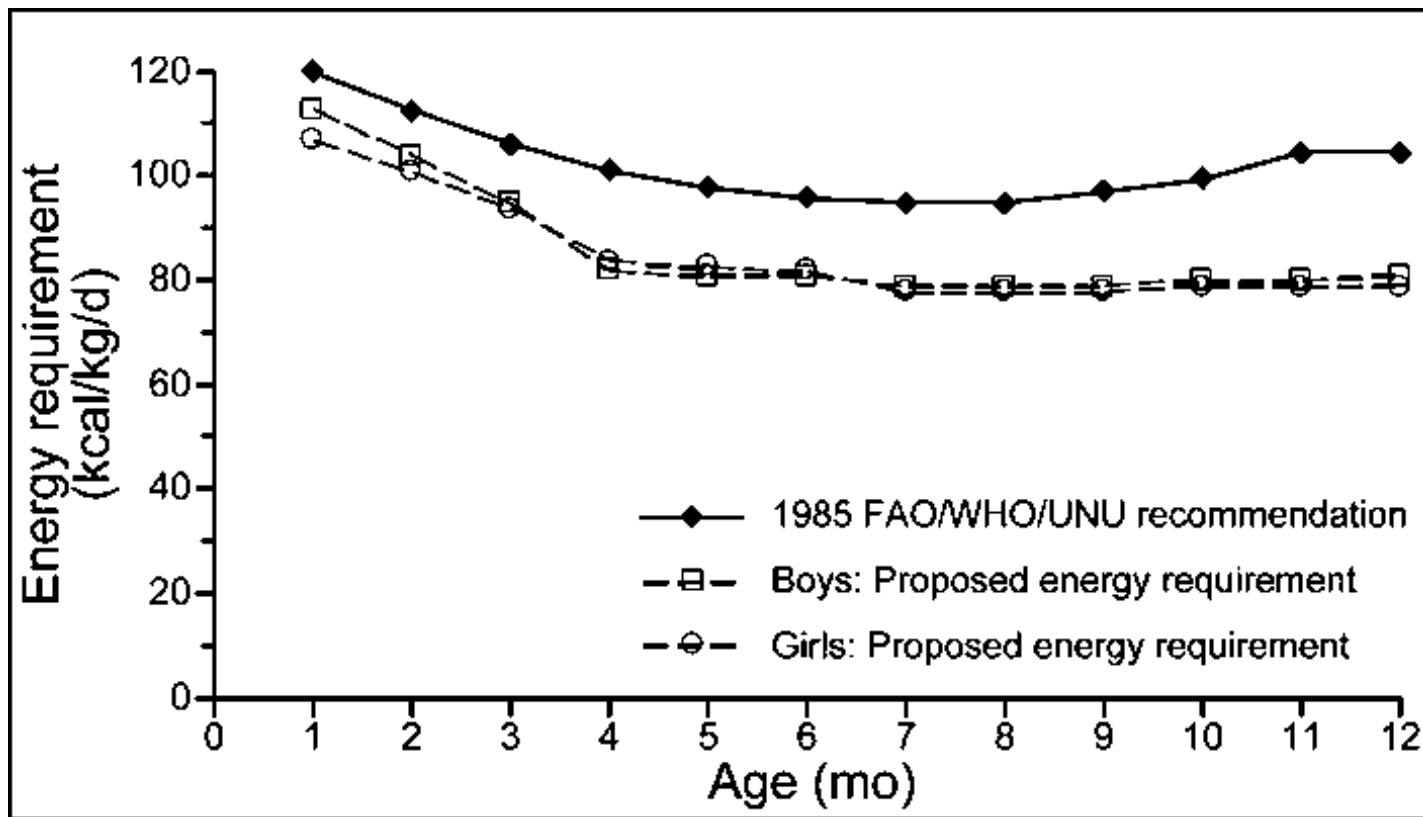
3.4.2 Basal metabolic rate and physical activity level

The 1981 FAO/WHO/UNU expert consultation estimated the energy requirements of adults as multiples of BMR (WHO, 1985). This was later called "physical activity level" (PAL) in a manual commissioned by FAO for the calculation of human energy requirements. PAL is defined as the total energy required over 24 hours divided by the basal metabolic rate over 24 hours (James and Schofield, 1990). The 2001 expert consultation upheld this approach to estimating requirements for adults (section 5). However, the approach must be used with caution or avoided altogether in relation to the energy requirements of infants and young children, as PAL values may cause confusion owing to differences in the factors that determine energy requirements among children and among adults. In non-pregnant, non-lactating women energy requirements are equal to TEE. In children, however, energy requirements are equal to TEE plus energy accrued or deposited during growth (E_g). These differences are quantitatively small after two years of age, when E_g represents less than 1 or 2 percent of the total energy requirement of the child; but they are increasingly larger at less than two years of age. For example, E_g is about 40 and 23 percent of the energy requirement in the first and third months of life, respectively. Consequently, energy requirement expressed as a function of BMR is much higher (i.e. > 2.0 at one month of age and > 1.7 at three months) in comparison with a PAL value (which is based on measured total energy expenditure) of 1.2 and 1.3 respectively.

BMR of term infants has been studied extensively producing variable results that range from 180 to 250 kJ/kg/day (43 to 60 kcal/kg/day) (Butte, 2001). This high variability has been attributed to biological differences, mainly in body composition at different stages of infancy, and to differences in methods and experimental conditions. For example, some investigators measured "basal" metabolism in infants who were sleeping spontaneously or under the effect of a sedative, which decreases BMR, and others did the measurements in the fed state, which increases BMR. The 1981 expert consultation endorsed the use of predictive equations to estimate the BMR of children under three years of age, derived from approximately 300 data points obtained by a variety of investigators using different methods and under diverse conditions (Schofield, Schofield and James, 1985). These equations underestimate BMR by about 5 to 12 percent from one to nine months of age (Butte, 1989; Wells *et al.*, 1996). This could partly be owing to the lack of uniformity in the conditions when BMR was measured, and hence could have an important impact on the calculation of PAL.

FIGURE 3.2

Comparison of present estimates of energy requirements of infants (combining breastfed and formula-fed infants) with those in the 1985 FAO/WHO/UNU report



Source: Butte, 2001.

3.5 Catch-up growth

Assessment of requirements and dietary recommendations for premature, small for gestational age and malnourished infants is beyond the scope of this report. The consultation recognized, however, that many populations around the world have large numbers of newborns with intrauterine growth retardation, and malnourished children less than one year of age. In addition to proper health, social and emotional support, these infants require special nutritional care for a rapid, catch-up growth that will allow them to attain the expected weight and height of normal children born with adequate size at term, and who have never been malnourished. To this end, high growth velocities can be achieved that, compared with the weight gain of normal, well-nourished children, can be up to 20 times higher among underweight, wasted children and about three to five times higher among short, stunted infants.

Diets for catch-up growth must provide all nutrients and energy sources in amounts that are proportionally higher than those required by well-nourished infants of adequate size. However, it is difficult to generalize about the quantitative energy requirements for catch-up growth, as these must often be assessed on an individual basis. Dietary needs, and hence recommendations, may vary with the extent of and the causes of growth retardation, which include the duration of pregnancy; metabolic, physiological and nutritional alterations during intrauterine development; pre- and postpartum infections; and pre- and postpartum primary or secondary malnutrition. The age of onset and duration of the causes leading to growth retardation must also be considered for appropriate dietary interventions. Because the target body weight and length are not fixed but increase with time in a growing child, the longer the period of growth deficit, the greater the gap to be filled.

There are conflicting reports on whether BMR is depressed in severely malnourished children (Montgomery, 1962; Parra *et al.*, 1973) and rises in the early stages of

nutritional rehabilitation. Studies with DLW (Fjeld and Schoeller, 1988) suggest that during the early phases of recovery TEE is about 5 to 10 percent higher than expected in well-nourished children, and this increment disappears in the late stages of nutritional treatment. This is probably a reflection of the accelerated rates of tissue synthesis and deposition. There are also reports with varying results on whether the rate of catch-up growth influences the composition of weight gain in children treated for severe malnutrition. Most agree that during the early phases of recovery, 15 to 20 percent of the weight gain seems to be protein, with the rest equally divided between fat and water (Graham *et al.*, 1969; MacLean and Graham, 1980; Fjeld, Schoeller and Brown, 1989).

The influence of malnutrition and the effect of infections on energy requirements are further addressed in section 4.6 of this report, where tentative recommendations are made for populations with high prevalence of infant malnutrition.

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