Background Information

Daily energy expenditure (total energy expenditure) consists of basal metabolic rate (BMR), physical activity energy expenditure, and thermic effect of food (diet-induced thermogenesis). In children and infants, the need for additional energy for growth also requires determination of not only the energy necessary for meeting daily needs but also the energy necessary for increased tissue for growth (energy deposition) and the energy necessary for tissue formation. Of the two forms of energy required for growth, only energy for tissue formation is currently included in determination of total energy expenditure for children and infants. Therefore, to determine energy requirement, energy deposition needs to be added to total energy expenditure. Determining the energy requirement for pregnant women requires determination of the energy expenditure of the fetus and the energy necessary for the growth of fetal tissues. Determining the energy requirement for lactating women requires determination of the energy required to produce breast milk and consideration of weight loss corresponding to breast milk production. Therefore, increased or decreased energy requirements corresponding to an increase or decrease in tissue growth must be considered in addition to total energy expenditure, as reflected in the formula used to calculate energy requirements:

\[
\text{Energy requirement} = \text{total energy expenditure} + \text{energy for the increased or decreased tissue.}
\]

For adults undergoing no body weight change, no
additional energy is required above that for meeting daily needs. Therefore, when energy intake exceeds energy requirements, the unutilized energy substrate is accumulated mainly in adipose tissue as triglycerides. An increase in adipose tissue may increase body weight and body fat in the short term and lead to obesity, a risk factor for many lifestyle-related diseases and increased total mortality, in the long term. In contrast, an energy intake less than that of energy expenditure may cause a decrease in the amount of accumulated fat in adipose tissues and in the amount of body protein, such as that contained in muscle tissue; a decrease in bodily functioning and quality of life; and an increase in morbidity due to infectious disease and certain cancers as well as in total mortality. Therefore, the optimal energy intake of adults—their true energy requirement—is that equal to the amount of energy expended when they are at an appropriate body weight.

Determining DRI

Estimated energy requirement

In the determination of the Dietary Reference Intakes for Japanese (DRIs-J) for energy, the concept of estimated energy requirement (EER) was applied in the same way as it had been in determining the DRIs for the United States and Canada (1, 2). The EER is established for individuals and groups; the EER for individuals is defined as “habitual energy intake in a day which is predicted to have the highest probability that energy balance (energy intake—energy expenditure, in adults) becomes zero in an individual of a given age, sex, height, body weight, and level of physical activity in good health.”

When the energy intake of an individual is the same as the EER, the probability of inadequate intake—that the individual’s energy intake is below his/her true energy requirement—is 50% and the probability of excessive intake is 50%. For many nutrients, the probability of adequate energy intake decreases as energy intake decreases, and the probability of adequate energy intake increases as intake increases while remaining sufficiently below the UL. However, the probability of inadequate energy balance increases equally whether intake is below or above the EER. That is, the probability of weight gain increases when an individual’s energy intake is above the EER and the probability of weight loss increases when the individual’s energy intake is below the EER. For this reason, the DRI concepts used for determination of other nutrients cannot be applied to determination of energy requirements.

In contrast to that for individuals, the EER for a group is defined as “habitual energy intake in a day which is predicted to have the highest probability that energy balance (energy intake—energy expenditure, in adults) becomes zero in a group.” When the energy intake of a defined group is the same as the EER, the probability that the energy intake is below a group member’s true energy requirement is 50% and probability that the energy intake is above the requirement is 50%. The components with great impact on total energy expenditure are BMR and energy expenditure for physical activities. Therefore, determination of an accurate EER requires determination of the defined individuals’ or groups’ BMR and the amount of physical activity.

Physical activity level (PAL) is an index of level of physical activity that considers diet-induced thermogenesis, also. PAL is calculated as total energy expenditure divided by BMR (16–18), as shown in the following

<table>
<thead>
<tr>
<th>Sex</th>
<th>Males</th>
<th></th>
<th>Females</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Reference BMR (kcal/kg weight/d)</td>
<td>Reference weight (kg)</td>
<td>BMR (kcal/d)</td>
<td>Reference BMR (kcal/kg weight/d)</td>
</tr>
<tr>
<td>1–2 y</td>
<td>61.0</td>
<td>11.7</td>
<td>710</td>
<td>59.7</td>
</tr>
<tr>
<td>3–5 y</td>
<td>54.8</td>
<td>16.2</td>
<td>890</td>
<td>52.2</td>
</tr>
<tr>
<td>6–7 y</td>
<td>44.3</td>
<td>22.0</td>
<td>980</td>
<td>41.9</td>
</tr>
<tr>
<td>8–9 y</td>
<td>40.8</td>
<td>27.5</td>
<td>1,120</td>
<td>38.3</td>
</tr>
<tr>
<td>10–11 y</td>
<td>37.4</td>
<td>35.5</td>
<td>1,330</td>
<td>34.8</td>
</tr>
<tr>
<td>12–14 y</td>
<td>31.0</td>
<td>48.0</td>
<td>1,490</td>
<td>29.6</td>
</tr>
<tr>
<td>15–17 y</td>
<td>27.0</td>
<td>58.4</td>
<td>1,580</td>
<td>25.3</td>
</tr>
<tr>
<td>18–29 y</td>
<td>24.0</td>
<td>63.0</td>
<td>1,510</td>
<td>22.1</td>
</tr>
<tr>
<td>30–49 y</td>
<td>22.3</td>
<td>68.5</td>
<td>1,530</td>
<td>21.7</td>
</tr>
<tr>
<td>50–69 y</td>
<td>21.5</td>
<td>65.0</td>
<td>1,400</td>
<td>20.7</td>
</tr>
<tr>
<td>≥70 y</td>
<td>21.5</td>
<td>59.7</td>
<td>1,280</td>
<td>20.7</td>
</tr>
</tbody>
</table>

BMR, basal metabolic rate.
formula:

\[ \text{PAL} = \frac{\text{total energy expenditure (kcal/d)}}{\text{BMR (kcal/d)}} \]

The doubly labeled water (DLW) method, the most accurate method for measuring total energy expenditure that was employed in determining the DRIs of the United States and Canada, was utilized to determine the PAL for each sex and age group. Considering the range of inter-individual variability in energy expenditure based on individual characteristics and evidence, a number of PALs were established to calculate a more accurate EER.

4. Calculation of EER

Using PALs obtained from daily total energy expenditure of Japanese measured using the DLW method (19), the EER is calculated as follows:

\[ \text{EER (kcal/d)} = \frac{\text{BMR (kcal/d)}}{\text{PAL}} \]

For children, pregnant women, and lactating women, energy deposition is added to the EER to account for increased tissue due to growth, the products of conception and accretion of maternal tissues, and the energy costs corresponding to postpartum lactation and weight change, respectively.

5. Adults

In a study aimed at determining the PAL of Japanese adults \((n=139, \text{aged 20 to 59 y})\) (19), the subjects were divided into 3 groups using the 25th and 75th percentile values (1.60 and 1.90, respectively; Table 2). Based on the results of the stratification, the groups were labeled according to activity level as Level I (low activity level, representative value = 1.50), Level II (moderate activity level, representative value = 1.75), and Level III (high activity level, representative value = 2.00). According to this classification, the ratio of individuals allocated to each level could be roughly expressed as 1:2:1. As shown in Table 2, the mean ± standard deviation (SD) for the PAL of all subjects was 1.75 ± 0.22. The representative value (or mean) for Level I generally corresponds to the value (mean – 1 × SD) for the entire group and the representative value (or mean) for Level III to the value of (mean + 1 × SD).

According to the results of studies of total energy expenditure and PAL of the Japanese using the DLW method (19–33), the use of these 3 levels appears appropriate.

6. The elderly

Among the many studies that have attempted to determine the PAL of healthy, independently living elderly subjects (33–42), the mean value was 1.69, leading the reference PAL for elderly subjects to be set at 1.70. However, the subjects’ mean age in most of these reports (11 out of 13) ranged from 70 to 75 y, and many examined only relatively healthy independently living elderly subjects. These facts, as well as the fact that few studies have examined the average PAL of subjects in their 90s, makes it difficult to identify reference PALs for the elderly over 70 y. One report (43) found that the PAL of subjects in their 90s tends to be low.

7. Children

Children in the growth stage require energy not only for physical activity but also for tissue formation and increased tissue (energy deposition). As the energy used for tissue formation is included in the calculation of total energy expenditure, the EER (kcal/d) was calculated as follows:

\[ \text{EER (kcal/d)} = \frac{\text{BMR (kcal/d)}}{\text{PAL} + \text{energy deposition (kcal/d)}} \]

As PALs differ by age group, a systematic review was conducted of reports of children’s PALs using the DLW method. Values of PAL were determined based on reports with measured BMR data (44–66). For children younger than 5 for whom such data were unavailable, PAL values were also based on estimated BMR (31, 67–74). The mean PAL was found to be 1.36, 1.47, 1.57, 1.59, 1.63, 1.66, and 1.76 for ages 1 to 2 y, 3 to 5 y, 6 to 7 y, 8 to 9 y, 10 to 11 y, 12 to 14 y, and 15 to 17 y, respectively, showing a tendency to increase with age (Fig. 1). The Grouping of PALs at each age group is shown in Table 3. The similar tendency was observed in a systematic review (75).

Although individual variability was observed for ages 1 to 2 y and ages 3 to 5 y, the PALs for these groups were not categorized into levels due to the lack of data for categorizing PAL for individuals or groups. In contrast, the PALs for those aged 6 and over were categorized into 3 levels to consider individual variability. The means of the standard deviation of selected references weighted by the number of subjects based on age group differed in the range 0.17 to 0.25, with a mean value of 0.21. Therefore, the PAL in each age group of children was increased or decreased by 0.20 from the corresponding group’s “moderate” value. As there were no data regarding PAL for these age groups in Japan, Level I (low) was established for school-age children for the first time, with consideration of the wide variations in PAL reported in previous studies conducted in foreign countries. In the future, the status and determinants of the PALs of Japanese school-age children need to be studied.

### Table 2. BMI and PAL at each physical activity level (mean ± SD).

<table>
<thead>
<tr>
<th>PAL (range)</th>
<th>n</th>
<th>Sex ratio (% male)</th>
<th>Age (y)</th>
<th>BMI (kg/m²)</th>
<th>PAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I (&lt;1.6)</td>
<td>38</td>
<td>55</td>
<td>40±11</td>
<td>23.9±2.5</td>
<td>1.50±0.08</td>
</tr>
<tr>
<td>Level II (≥1.6, ≤1.9)</td>
<td>65</td>
<td>52</td>
<td>39±11</td>
<td>22.8±3.1</td>
<td>1.74±0.08</td>
</tr>
<tr>
<td>Level III (&gt;1.9)</td>
<td>36</td>
<td>39</td>
<td>40±9</td>
<td>21.3±2.6</td>
<td>2.03±0.13</td>
</tr>
<tr>
<td>Total</td>
<td>139</td>
<td>50</td>
<td>39±10</td>
<td>22.7±2.9</td>
<td>1.75±0.22</td>
</tr>
</tbody>
</table>

n, number of subjects; BMI, body mass index; PAL, physical activity level.
Energy for increased tissue was determined as the product of increased weight per day calculated from the reference weight and the energy density of increased tissue \((1)\) (refer to Table 4 for details).

8. Infants

For infants, as for older children, energy is required for not only physical activity but also tissue formation and energy deposition. As the energy required for tissue formation is included in total energy expenditure, the EER was calculated as follows:

\[
\text{EER (kcal/d)} = \text{total energy expenditure (kcal/d)} + \text{energy deposition (kcal/d)}.
\]

For determining the total energy expenditure of infants, the Food and Agricultural Organization (FAO), World Health Organization (WHO), and United Nations University (UNU) have reported that total energy expenditure of breast-fed infants can be modeled by the following regression equation, which uses body weight as an independent variable and considering the relationships among sex, age (months), body weight, body height, and total energy that were identified in previous studies \((76, 77)\):

Total energy expenditure (kcal/d)
\[
= 92.8 \times \text{reference weight (kg)} - 152.0.
\]

As no study has determined Japanese infants’ total energy expenditure using the DLW method, total energy expenditure was determined by substituting the reference weights of the Japanese into the regression equation. As with children, energy deposition is calculated as the product of increased weight per day as calculated using the reference weight and energy density of increased tissue for infants \((67)\) (Table 4).

The EER is determined for infants at 3 different ages: 0 to 5 mo, 6 to 8 mo, and 9 to 11 mo. For infants aged 0 to 5 mo who undergo large weight changes, attention must be placed on the large difference in the EER between the first and second half of this period. As formula-fed infants typically have greater total energy expenditure than breast-fed infants \((76, 77)\), the FAO, WHO, and UNU have reported that the EER of formula-fed infants should be determined using the following regression equation \((76, 77)\):

Total energy expenditure (kcal/d)
\[
= 82.6 \times \text{body weight (kg)} - 29.0.
\]

9. Additional values for pregnant women

The EER of pregnant women is calculated as follows:

\[
\text{EER (kcal/d)} = \text{EER before pregnancy (kcal/d)} + \text{additional energy required by pregnant women (kcal/d)}.
\]

Considering that the female reproductive period encompasses several age groups, it is necessary to determine the additional amounts of energy needed to maintain good health during pregnancy and for normal delivery for each stage of pregnancy. Longitudinal studies using the DLW method found that although PAL decreases during the early and late stage of pregnancy, increased rates of total energy expenditure during the early, mid, and late stage of pregnancy correspond to increased rates of weight gain, as does an increase in BMR during the late stage of pregnancy \((76–82)\). Therefore, differences between pre-pregnancy EER and total energy expenditure during each stage \((76, 77)\) adjusted by an average total weight gain of 11 kg during pregnancy \((83)\) are as follows: +19 kcal/d during the early stage, +77 kcal/d during the mid-stage, and +28.5 kcal/d during the late stage. Total energy deposition is calculated as the sum of energy deposition of protein and fat that yields a final weight gain of 11 kg, based on protein deposition and body fat deposition on a per-stage basis \((76, 77)\). Thus, energy deposition is 44 kcal/d during the early stage, 167 kcal/d during the mid-stage, and 170 kcal/d during the late stage.

As a result, total additional energy for each stage is calculated as follows:

Additional energy for pregnant women (kcal/d)
When the final values are rounded into 50-kcal units, an additional 50 kcal/d is required during the early stage, 250 kcal/d during the mid-stage and 450 kcal/d during the late stage.

10. Additional values for lactating women

The EER of lactating women is calculated as follows:

\[ \text{EER (kcal/d)} = \text{EER before pregnancy (kcal/d)} + \text{additional energy required by lactating women (kcal/d)} \]

Although BMR is considered to be elevated immediately after delivery, primarily due to the 2 processes of maintenance of increased body weight compared to prepregnancy weight and breast milk production, an obvious increase in BMR is not observed. Of 4 longitudinal studies using the DLW method, 1 reported that energy expenditure by physical activity decreased significantly (78) whereas the other 3 reported a 10% decrease in absolute quantity but no significant difference was observed (79, 81, 84). These findings indicate that total energy expenditure during lactation is the same as that during pregnancy (77, 79, 81, 84). Regarding change in total energy expenditure, there is no need to calculate an additional value for lactating women. Meanwhile, lactating women must intake additional energy for breast milk production since it is not included in total energy expenditure.

Assuming that the amount of breast milk secreted is equal to the amount suckled by the infant (0.78 L/d) (85, 86) and that breast milk provides 663 kcal/L (87), the following equation can be used to determine the total energy provided by breast milk:

\[ \text{Total energy provided by breast milk (kcal/d)} = \frac{0.78 \times 663}{365} \times 2.3 \quad \text{(kcal/g)} \]

\[ \approx 12 \text{ kcal/d} \]
6,500 kcal/kg body weight
\[ \times 0.8 \text{ kg/mo} = 30 \text{ d} \]
\[ \approx 173 \text{ kcal/d.} \]

Therefore, the additional energy required by lactating women who have experienced a normal pregnancy and delivery is calculated as follows:

Additional energy required by lactating women (kcal/d) = breast milk energy (kcal/d) – energy of weight loss (kcal/d).

Thus, the additional energy required for breast-feeding is 517–173 = 344 kcal/d, which, when rounded by 50-kcal units, is 350 kcal/d.

Table 5. PAL of adults aged 15 to 69 y during daily activities for typical durations.\(^1\)

<table>
<thead>
<tr>
<th>PAL(^2)</th>
<th>Low level (I)</th>
<th>Moderate level (II)</th>
<th>High level (III)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.50 (1.40–1.60)</td>
<td>1.75 (1.60–1.90)</td>
<td>2.00 (1.90–2.20)</td>
</tr>
<tr>
<td>Description of activity(^3)</td>
<td>Subjects largely remain sedentary and perform activities that require low expenditure.</td>
<td>Subjects largely remain sedentary but perform any of the following: moving within the workplace, working while standing, serving customers, commuting, shopping, housekeeping, and participating in light sport activities.</td>
<td>Subjects engage in work that requires moving or standing or habitually engage in active athletic activities.</td>
</tr>
<tr>
<td>Types of each activity (h/d)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleeping (0.9)(^4)</td>
<td>7–8</td>
<td>7–8</td>
<td>7</td>
</tr>
<tr>
<td>Remaining sedentary or remaining still while standing (1.5: 1.0–1.9)(^4)</td>
<td>12–13</td>
<td>11–12</td>
<td>10</td>
</tr>
<tr>
<td>Engaging in slow walking or light intensity activities, such as housekeeping (2.5: 2.0–2.9)(^4)</td>
<td>3–4</td>
<td>4</td>
<td>4–5</td>
</tr>
<tr>
<td>Performing moderate-intensity activities that can be sustained for an extended period, including normal walking (4.5: 3.0–5.9)(^4)</td>
<td>0–1</td>
<td>1</td>
<td>1–2</td>
</tr>
<tr>
<td>Performing vigorous activities that require frequent rest (7.0: ≥6.0)(^4)</td>
<td>0</td>
<td>0</td>
<td>0–1</td>
</tr>
</tbody>
</table>

PAL, physical activity level.
\(^1\)The values presented are the standard values for each activity based on the PALs obtained using the DLW method and BMR, and the hours from 3 d of activity records for adult subjects living in Tokyo and its suburbs.
\(^2\)Representative values. The range is shown in parentheses.
\(^3\)Prepared using Black et al. (17) as a reference and giving due consideration to the significant effects of occupation on PAL.
\(^4\)Data in parentheses are MET values (representative value: lower threshold–upper threshold).

**Application**

**Concept of reference basal metabolic rate**

Reference basal metabolic rate (reference BMR) is designed such that the estimated value corresponds to a measured value for a reference physique. Therefore, for individuals with a body physique largely different from the reference physique, the prediction error tends to be large. Among the Japanese, for example, the BMR tends to be overestimated when the reference BMR is applied to obese individuals (88) and underestimated when applied to lean individuals. An EER obtained by multiplying an overestimated or underestimated BMR and PAL would have a high possibility of being above the...
true requirement for an obese individual and below that for a lean individual. Thus, designing an energy intake plan based on such an EER would increase the probability of further obesity or leanness in such individuals.

**Relationship between reference BMR and fat-free mass**

BMR has been found to be more strongly associated with fat-free mass (FFM) than body weight (5, 8, 11, 89). In the future, the combined use of adequate body composition assessment and corresponding predictive equations will likely yield more accurate estimation of BMR.

**Measurement errors in the EER**

In the DRIs for the United States and Canada (1, 2), the standard error of estimate of total energy expenditure is approximately 300 kcal/d for males. Assuming this variability is divided into biological and experimental variances, such as measurement error in using the DLW method, and that both variances are equal, biological variability can be estimated at approximately ±200 kcal/d as a standard deviation. Thus, when EER is calculated as 2,500 kcal/d, the probability of the true energy requirement being between 2,300 and 2,700 kcal/d is approximately 68% and of being between 2,100 and 2,900 kcal/d approximately 95%. In other words, if the EER were 2,500 kcal/d, 1 out of 3 individuals’ true energy requirement would be below 2,300 kcal/d or above 2,700 kcal/d.

**Physical activity level**

Metabolic equivalent (MET), a multiple of the resting metabolic rate in the sitting position, was used as physical activity intensity to estimate PAL rather than activity factor (Af), a multiple of BMR (90). This was done to avoid confusion in using MET and Af representing physical activity intensity. As fasting BMR in the sitting position is approximately 10% higher than the resting metabolic rate in the supine position (1, 90), MET is calculated as follows:

\[
\text{MET value} = 3 \times \frac{1.1}{\text{Af}}.
\]

The PAL of adults aged 15 to 69 y during the performance of daily activities for typical durations is shown in Table 5.

**Effect of excessive post-exercise oxygen consumption on total energy expenditure**

In the DRIs for the United States and Canada, excessive post-exercise oxygen consumption (EPOC), which is assumed to be 15% of certain activities, was added to calculate the EER in addition to energy expenditure during physical activity. However, EPOC was not added to the DRIs-J because it is considered to be very small in daily life (91). Therefore, only energy expenditure during certain activity was considered energy expended during physical activity in the DRI-Js. The EER values for
each sex and age group are shown in Table 6.

REFERENCES


