How much may I eat? Calorie estimates based upon energy expenditure prediction equations

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Summary
How much may I eat? Most healthcare workers, when asked this question, have insufficient knowledge to educate their patients on a healthy energy intake level. In this review we examine the available methods for estimating adult energy requirements with a focus on the newly developed National Academy of Sciences/Institute of Medicine (NAS/IOM) doubly-labelled water total energy expenditure (TEE) prediction equations. An overview is first provided of the traditional factorial method of estimating energy requirements. We then extend this overview by exploring the development of the NAS/IOM TEE prediction models and their role in estimating energy requirements as a function of sex, age, weight, height and physical activity level. The NAS/IOM prediction models were developed for evaluating group energy requirements, although the formulas can be applied in individual ‘example’ patients for educational purposes. Potential limitations and interpretation issues of both the factorial and NAS/IOM methods are examined. This information should provide healthcare professionals with the tools and understanding to appropriately answer the question, ‘How much may I eat?’

Keywords: Obesity, body composition, nutritional requirements, calorie intake.

Introduction
How much may I eat? This might be a reasonable question posed by patients to their healthcare workers in light of the ever-growing publicity surrounding weight control (1). The energy contents of foods in kilocalories (kcal) are printed on product labels (2), the energy expenditure of various physical activities are widely reported in the lay press and the new food pyramid now includes an activity component (3), and popular diets tout appropriate intakes of one macronutrient or another (4). However, there remains limited knowledge among healthcare workers outside the expert nutrition community on how to answer the question, ‘How much may I eat?’.

Unfortunately, answering this question is not simple, even for experts. Remarkably, until relatively recently, the actual energy intake of humans living and working within their natural environments was at best a rough estimate. A time-honoured approach for estimating energy intake was and is based on subject-recorded food diaries. However, food diaries may not only be inaccurate at the individual level, but are notably biased in populations such as the obese or in-patients with anorexia nervosa who tend to under and overestimate what they eat (5,6) respectively.

The aim of this overview is to provide clinicians with the rationale and background information needed to advise patients on their energy requirements. We first examine methods of estimating food intake and energy expenditure. The review then provides the scientific foundation and methods for estimating a subject’s energy requirements as they vary with sex, age, weight, height and physical activity level (PAL). Unresolved questions or critical issues in answering the question, ‘How much may I eat?’, are examined as a means of providing the reader with the strengths and potential limitations of available food intake prediction formulas.
Estimating energy requirements

Factorial method

Energy intake and energy output are equivalent when non-growing, non-lactating healthy adults are in weight balance over time, and estimates of energy expenditure thus provide an alternative method of quantifying energy intake from foods (7). The approach widely applied by investigators is to estimate food intake in subjects living within their natural environments using a ‘factorial’ method. Energy expenditure in weight-stable adults living under thermoneutral conditions is usually considered as consisting of three main components, resting or basal energy expenditure (REE), the thermic effect of food or diet-induced energy expenditure (DEE) and the energy expended in physical activity (AEE) (8). Additional components are also sometimes considered in special circumstances, such as the energy expended in thermoregulation and in building new tissues or producing milk. A subject’s REE and DEE can both be measured in the laboratory by indirect calorimetry (9). The DEE, lasting for several hours after a meal, is relatively small, about 5–10% of daily energy intake, and is usually estimated rather than measured (10).

The energy expended in each physical activity (PA) can also be measured by indirect calorimetry in the laboratory and the subject is then asked to keep an activity diary while living within their natural environment. The recorded activities along with their duration are used to estimate AEE. More advanced methods can be used to monitor physical activities, such as accelerometers, pedometers, or electronic heart rate counters (11). Another reported component of energy expenditure is non-exercise activity thermogenesis (NEAT), or the ‘fidget factor’. NEAT may be a significant contributor to energy needs and thus confounds estimates of AEE based on diaries and energy costs of common physical activities (12).

The three energy expenditure components are then summed to provide a measure of total energy expenditure (i.e. TEE = REE + DEE + AEE) and thus energy intake from foods under conditions of energy and weight equilibrium.

Simplified factorial methods are widely used in clinical nutrition practice. The usual approach is to apply an equation for estimating REE that includes predictor variables such as body weight, height, age and sex (13,14). A critical analysis of REE prediction methods is presented in the review of da Rocha et al. (15). The DEE is either ignored because of its small magnitude or calculated using simple prediction formulas (10). The AEE is derived from a patient history and TEE is then calculated from the estimated components. Additional factors, such as energy expended in catabolic states or with fever, may be used to refine the estimate in-patients with medical conditions (16).

An example of the factorial method for estimating group energy requirements was recently jointly published by the Food and Agriculture Organization (FAO), World Health Organization (WHO) and United Nations University (UNU) (17). The FAO/WHO/UNU TEE prediction model accounts for two energy expenditure terms, REE and AEE. The small DEE term is not considered in the TEE prediction model.

REE is first calculated from the subject’s sex, weight, height and age (Table 1) (17). The equations with related standard errors of the estimate (SEE) presented in Table 1 were developed in healthy subjects using indirect calorimetry to measure REE. The SEEs of predicted REE range from ~100–200 kcal d\(^{-1}\), and thus individual estimates are not very accurate. If indirect calorimetry equipment is available, REE can also be measured, thus providing a more accurate estimate for the individual subject than the prediction formulas presented in Table 1.

The next step is to quantify the subject’s level of occupational and recreational PA. The usual approach is for the subject to record the types and duration of activities over a period of one or more representative days. Once completed, the record is analysed by first expressing the energy cost of each activity as a ratio to measured or predicted REE, referred to as the physical activity ratio (PAR) and expressed in multiples of REE per hour. For example, the energy cost or PAR of walking is 3.2, implying that walking at varying paces without a load approximately leads to a threefold increase in REE. The energy cost of various activities can be found in published tables (18) and some representative examples are provided in Table 2 and in Annex 5 of the FAO/WHO/UNU report (17). The energy expended for the activity over 24 h is...

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**Table 1** Equations for estimating REE from body weight

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>No.</th>
<th>REE (kcal d(^{-1}))</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;3</td>
<td>162</td>
<td>59.512 × BW – 30.4</td>
<td>70</td>
</tr>
<tr>
<td>3–10</td>
<td>338</td>
<td>22.706 × BW + 504.3</td>
<td>67</td>
</tr>
<tr>
<td>10–18</td>
<td>734</td>
<td>17.686 × BW + 658.2</td>
<td>105</td>
</tr>
<tr>
<td>18–30</td>
<td>2879</td>
<td>15.057 × BW + 692.2</td>
<td>153</td>
</tr>
<tr>
<td>30–60</td>
<td>646</td>
<td>11.472 × BW + 873.1</td>
<td>167</td>
</tr>
<tr>
<td>≥60</td>
<td>50</td>
<td>11.711 × BW + 587.7</td>
<td>164</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;3</td>
<td>137</td>
<td>58.317 × BW – 31.1</td>
<td>59</td>
</tr>
<tr>
<td>3–10</td>
<td>413</td>
<td>20.315 × BW + 485.9</td>
<td>70</td>
</tr>
<tr>
<td>10–18</td>
<td>575</td>
<td>13.384 × BW + 692.6</td>
<td>111</td>
</tr>
<tr>
<td>18–30</td>
<td>829</td>
<td>14.818 × BW + 486.6</td>
<td>119</td>
</tr>
<tr>
<td>30–60</td>
<td>372</td>
<td>8.126 × BW + 845.6</td>
<td>111</td>
</tr>
<tr>
<td>≥60</td>
<td>38</td>
<td>9.082 × BW + 658.5</td>
<td>108</td>
</tr>
</tbody>
</table>

Weight is expressed in kg. Predictive equations for children and adolescents are presented for completeness.

REE, resting or basal energy expenditure; SEE, standard error of the estimate. Modified from reference (17).
then calculated as the product of PAR and time (expressed in hours) spent in the activity. The time $\times$ energy cost values are summed across all activities, including sleep and divided by 24 as a measure of TEE/REE, and is referred to as the PAL.

PALs range from a low of about 1.2 to over 4 in highly trained athletes and soldiers (17). The profile of a typical low or ‘sedentary’ PAL is presented in Table 2. For convenience, PALs can be grouped into three categories, low, medium and high as outlined in Table 3. An excellent in-depth discussion of the PAL concept can be found on the National Academies Press web site (http://www.nap.edu/books/0309085373/html/697.html).

The final step in estimating TEE is to take the product of PAL and REE as: $\text{TEE} = \text{PAL} \times \text{REE}$. A rough idea of an adult’s energy requirement for maintaining weight stability can thus be calculated from their weight, height, age and sex for REE (Table 1) and to then estimate PAL from Table 3. For example, a sedentary person (i.e. PAL $\sim 1.5$) with REE of 1600 kcal d$^{-1}$ has an estimated TEE of 2400 kcal d$^{-1}$. This is the approximate amount the person would need to eat in order to maintain their body weight. Measuring REE by indirect calorimetry and PA with a diary or accelerometer would improve the TEE estimate’s accuracy. The variation in energy requirements around the midpoint of PAL ranges identified in Table 3 is $\pm 8$–10%. More advanced methods are available for predicting TEE from electronically measured motion over 24 h (11).

The traditional research-level factorial approach for estimating how much subjects eat has obvious limitations and inaccuracies. These include the brief (<1 h) REE measurement that must be extrapolated to 24 h, the DEE estimate based on a single meal study measured by indirect calorimetry, an assumed daily value, or ignored, and the approximation of AEE based on self-report.

The food diary, factorial and other related methods remain in use today, although accurate and unbiased assessment of actual energy requirements is now established by the ‘doubly labelled water’ method (19). The doubly labelled water method is the reference for measuring TEE in a free-living environment and thus a subject’s actual energy intake during weight stability.

### Table 2: Factorial calculations of TEE for a population group with sedentary or light activity lifestyle

<table>
<thead>
<tr>
<th>Main daily activities</th>
<th>Time allocation (h)</th>
<th>Energy cost (PAR)</th>
<th>Time $\times$ energy cost</th>
<th>Mean PAL* (TEE/REE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeping</td>
<td>8</td>
<td>1</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Personal care (dressing, showering)</td>
<td>1</td>
<td>2.3</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Eating</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Cooking</td>
<td>1</td>
<td>2.1</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Sitting (office work, selling procedure, tending shop)</td>
<td>8</td>
<td>1.5</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>General household work</td>
<td>1</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Driving car to/from work</td>
<td>1</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Walking at varying paces without a load</td>
<td>1</td>
<td>3.2</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Light leisure activities (watching TV, chatting)</td>
<td>2</td>
<td>1.4</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>36.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy costs of activities, expressed as multiples of REE, or PAR, are based on Annex 5 of the WHO consultation’s report (17).

*PAL is physical activity level, or energy requirement expressed as a multiple of 24-h REE. From (17).

TEE, total energy expenditure; REE, resting or basal energy expenditure; PAR, physical activity ratio.

### Table 3: Classification of lifestyles in relation to the intensity of habitual physical activity level (PAL = TEE/REE)

<table>
<thead>
<tr>
<th>Category</th>
<th>PAL value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary or light activity lifestyle</td>
<td>1.40–1.69</td>
<td>People who do not have occupations that demand much physical effort, are not required to walk long distances, generally use motor vehicles for transportation, do not exercise or participate in sports regularly, and spend most of their leisure time sitting or standing with little body displacement.</td>
</tr>
<tr>
<td>Active or moderately active lifestyle</td>
<td>1.70–1.99</td>
<td>People who have occupations that are not strenuous in terms of energy demands, but involve more energy expenditure than that described for sedentary lifestyles. Alternatively, they can be people with sedentary occupations who regularly spend time in moderate to vigorous physical activities, during either the obligatory or the discretionary part of their daily routine.</td>
</tr>
<tr>
<td>Vigorous or vigorously active lifestyle</td>
<td>2.00–2.40*</td>
<td>These people engage regularly in strenuous work or in strenuous leisure activities for several hours.</td>
</tr>
</tbody>
</table>

*PAL values > 2.40 are difficult to maintain over a long period of time.
Doubly labelled water method

Lifson and his colleagues in 1949 (20) first reported that the source of oxygen in carbon dioxide released during oxidative metabolism is water. Lifson and others who followed him advanced the concept that whole-body carbon dioxide production can be estimated by evaluating the rate of $^{18}$O disappearance from the stable isotope H$_2^{18}$O (21). Another stable water isotope, deuterium, is used to trace body losses of water and carbon dioxide production is then calculated as the difference between H$_2^{18}$O and H$_2$O disappearance over time (22). TEE can be derived from carbon dioxide production by making several assumptions about the nature of metabolized fuels over a specified time period (22). Lifson’s ‘doubly labelled water’ method, later advanced for human use by Schoeller and his colleagues in the 1980s (21), has been widely validated and applied in both animals and humans.

The doubly labelled water method as applied in humans requires ingestion of the two water isotopes at baseline and collection of urine samples at varying time intervals thereafter. The ‘two-point’ method requires a baseline and follow-up urine sample, usually taken in adult humans 14 d following isotope ingestion (22). TEE is then calculated over the 14-d interval and typically expressed as kcal expended per 24 h.

Assuming the subject’s weight remains stable over the 14-d doubly labelled water period, the measured TEE represents daily metabolizable energy intake from foods. Metabolizable energy is the energy content of food (i.e. carbohydrate, fat and protein at 4, 9 and 4 kcal/g) after adjusting gross energy intake for digestive and metabolic energy losses. Small adjustments can also be made to this estimate of energy intake if there are fluctuations in energy stores as reflected by changes in weight or body composition over the study period (23).

As distinct from food intake records, the doubly labelled water method provides an unbiased and accurate chronicle of subject food intake (22,23). The method was a major breakthrough in the study of animal and human energy requirements. However, the doubly labelled water method is costly to apply and the $^{18}$H$_2$O is not always readily available. The world literature is thus relatively small, approaching about 4000 total subjects.

In addition to an objective estimate of energy intake from foods, the doubly labelled water method also provides a measure of PALs (22). Non-volitional energy expenditure as the REE and DEE can be measured by indirect calorimetry. The AEE is then calculated as the difference between TEE and non-volitional energy expenditure (i.e. REE and DEE). Another approach for deriving an estimate of activity levels is to measure REE and then calculate the PAL as TEE/REE. As noted earlier and shown in Table 3, the PAL provides a measure of occupational and recreational activity. Doubly labelled water combined with conventional indirect calorimetry measurements are considered as the reference for quantifying activity levels in animals and humans living within their natural settings (10).

National Academy of Sciences prediction formulas

The National Academy of Sciences (NAS), Institute of Medicine (IOM) as part of the Dietary Reference Intake report collected the available world data on doubly labelled water from over 20 investigators willing to participate (24). In addition to demographic data and TEE, some study databases also included REE measurements. After screening the data and selecting appropriate subjects, the NAS derived a series of TEE and REE prediction equations using doubly labelled water and indirect calorimetry, respectively, as the reference measurement methods (24). The sex-specific formulas require four predictor variables, weight, height, age and level of PA. Expressed as a coefficient, PA can be grouped for convenience into four categories: sedentary, low active, active and very active. The health implications of PALs are examined in Chapter 12 of the NAS/IOM report (24).

As with the FAO/WHO/UNU method, the NAS/IOM approach is based on empirical sex-specific formulas that include weight, height and a measure of PA as predictor variables (24). Age is also considered as a determinant of TEE in both methods.

An example of a NAS/IOM TEE prediction equation is presented in Table 4 for normal weight and overweight/obese men and women over the age of 19 years. These equations can be used to explore the interactions between a subject’s energy needs and their corresponding weight, height, age and level of PA. The numerical values for the four PA categories and examples of their relations to PAL.

Table 4 National Academy of Sciences equations for predicting total energy expenditure (TEE) and resting energy expenditure (REE) in normal and overweight/obese adults (age ≥ 19)

<table>
<thead>
<tr>
<th></th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>TEE = 864.9 – 7.2 x age + PA x (14.2 x weight + 503 x height) (±202)*</td>
</tr>
<tr>
<td></td>
<td>REE = 293.3 – 3.8 x age + 456.4 x height + 10.12 x weight (residual, ±156, $R^2 = 0.64$)*</td>
</tr>
<tr>
<td>Women</td>
<td>TEE = 387.7 – 3.1 x age + PA x (10.9 x weight + 660.7 x height) (±160)*</td>
</tr>
<tr>
<td></td>
<td>REE = 247.2 – 6.7 x age + 401.4 x height + 8.6 x weight (residual, ±156, $R^2 = 0.62$)*</td>
</tr>
</tbody>
</table>

PA is physical activity coefficient as summarized in Table 5. TEE and REE, kcal d$^{-1}$; age, year; weight, kg; and height, metre (24).

*Estimated SDs of TEE for individuals of specific age, height, weight and physical activity level category for within individual variability.

Residuals are differences between the observed and predicted REE (24).
and walking distances are shown in Table 5. The NAS/IOM equations are based on cross-sectional data and the information required for exploring long-term changes in TEE with growth and ageing data are unavailable at present. The table also provides the corresponding REE prediction equations for men and women. The TEE and REE confidence limits and $R^2$ values are summarized in the table, and again highlight the utility of energy expenditure prediction for groups and not individuals.

The TEE prediction equations can be used to examine and respond to questions posed to physicians and other healthcare workers by their patients. For example, what is the appropriate response when a physician or other healthcare worker is asked by a patient ‘how much (energy in kcal) may (or should) I eat?’ Are there methods for deriving estimates of patient energy requirements? If available, are there nuances to the interpretation of these estimates? We can examine these questions using several examples.

### How much may I eat?

The answer to this question depends on the subject’s sex, age, weight, height and activity level, as outlined by the TEE prediction equations. To explore each of these independent determinants of energy requirements, we begin with a representative subject and the model TEE with this subject as a starting point.

A 20-year-old normal-weight (55.5 kg – 122 pounds; height, 1.63 m – 64 inches; body mass index [BMI], 21 kg m$^{-2}$) woman visits her healthcare worker for a routine evaluation. The subject is physically active, both in her occupation and during recreational time. When discussing the importance of maintaining her weight in the healthy range, she asks her physician ‘How much (i.e. how many kcal) may I eat?’. We can first examine her current energy intake as her BMI is within the ‘normal range’ (i.e. 18.5–24.9 kg m$^{-2}$). We can then follow up for educational purposes with an analysis of how PA, stature, age and sex moderate energy requirements for weight maintenance. In a later section, we will examine the specific question ‘How much may I eat to lose and then maintain a lower body weight?’.

The subject’s current energy intake is derived as 2372 kcal d$^{-1}$ by application of the NAS/IOM TEE equation for women in Table 4 and the PA coefficient ‘active’ in Table 5. This level of energy intake will maintain her current weight over the short-term (i.e. months), and thus within the normal range.

### If I am less or more physically active?

What if the subject’s activity level was lower or higher than ‘active’, how much would she need to eat in order to maintain a stable weight? There are two defined lower activity levels (low active and sedentary) and one higher level (very active). As shown in Fig. 1, sedentary, low active and very active levels of PA would lead to TEE values of 1929, 2155 and 2675 kcal d$^{-1}$ respectively. The subject would thus need to have a 19.1% and 9.2% smaller energy intake in order to maintain her weight at the lower respective activity levels and a 12.7% larger intake to maintain her weight at the higher level of PA. Energy intake at the ‘very active’ PAL would be 746 kcal d$^{-1}$ or 27.9% larger than at the sedentary or lowest activity level.

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**Table 5** Physical activity groups for National Academy of Sciences (NAS) total energy expenditure (TEE) formula

<table>
<thead>
<tr>
<th>Physical activity group</th>
<th>Formula PA coefficient (M/F)</th>
<th>Physical activity level (PAL)</th>
<th>Representative activity (walking, ∼miles per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>1/1</td>
<td>≥1 and &lt;1.4</td>
<td>0</td>
</tr>
<tr>
<td>Low active</td>
<td>1.12/1.14</td>
<td>≥1.4 and &lt;1.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Active</td>
<td>1.27/1.27</td>
<td>≥1.6 and &lt;1.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Very active</td>
<td>1.54/1.45</td>
<td>≥1.9 and &lt;2.5</td>
<td>16.7</td>
</tr>
</tbody>
</table>

*Estimates are for 70-kg adult walking at a rate of 2–4 miles h$^{-1}$ and above those of other activities that are part of a normal daily life.

IOM, Institute of Medicine; M, male; F, female; PA, physical activity coefficient as applied in the NAS/IOM TEE prediction formula; PAL, physical activity level, the ratio of TEE to REE. From (24).
This example can be used to examine the relations between foods eaten and energy requirements. We can assume in the context of this overview that the initial patient was eating four average-sized apples per day as part of her usual diet and that each apple provides about 100 kcal. We can also equate this to a plain donut which provides ~200 kcal and two donuts have the same energy content as four apples. To maintain the same weight as our subject who is ‘active’ and eats four apples or two donuts per day, the sedentary subject would have to give up eating apples (or donuts) and the low active subject could eat two apples (one donut). The very active subject would need to eat an extra three apples (1.5 donuts) per day to maintain her weight stable.

Body weight remains stable over long time when energy intake balances TEE. For example, the very active subject who is identical in age and height to the sedentary subject would need to eat 2738 apples or 1369 donuts to maintain the same weight over the course of 1 year. When considered over long time, even very small sustained deviations in energy balance can lead to large changes in body weight. We will again examine this important concept in a later section.

The importance of this demonstration is that energy requirements in relation to PA can be quantitatively equated with the amounts and quality of foods eaten. Apples and donuts are only simple examples that serve to demonstrate how activity-related effects on TEE can be translated to actual foods eaten by an individual subject.

If I weigh less or more?

The subject’s weight is within the healthy range for her height. What if she weighed less or more, how much would her energy requirements for weight maintenance differ? We can examine this question by calculating energy requirements for the traditional BMI cut-points of 18.5, 24.9, 30 and 40 kg m\(^{-2}\) that separate subjects into underweight, normal weight, overweight, obese and morbidly obese groupings. Compared with our reference subject with BMI 21 kg m\(^{-2}\), the subjects at lower or higher BMIs would have respective energy requirements for weight maintenance of 2281 (~4%), 2517 (+6%), 2703 (14%) and 3068 (+29%) kcal d\(^{-1}\) (Fig. 2). The heaviest subject would eat 787 kcal d\(^{-1}\) or 35% more than the leanest subject.

The weight-related differences in energy intake can also be translated for descriptive purposes into foods eaten as in the previous example. Compared with our reference subject with BMI 21 kg m\(^{-2}\), the lean subject with BMI 18.5 would eat ~1 less apple or 1⁄2 donut each day. On the other hand, the subjects with BMIs of 24.9, 30 and 40 kg m\(^{-2}\) would eat about 1.5, 3.5 and 7 more apples or 3⁄4, 13⁄4 and 31⁄2 more donuts respectively.

For the same age, height and PAL, the heaviest subject would eat 2873 more apples or 1436 more donuts per year compared with the leanest subject. Accurate data on PALs in the general population are limited, but it is likely that most morbidly obese persons are less physically active than their leaner counterparts. Any difference between subjects in their level of PA will translate to differences in energy requirements. An important consideration is that these examples represent predicted values that are useful for group comparisons but that have a large confidence limit when applied to individual subjects.

If I was shorter or taller?

What would happen to the subject’s energy requirements if she was shorter or taller? At the same weight, BMI would be larger if the subject was shorter and smaller if she was taller. If we examine the REE prediction equations in Table 4, we see that for every metre change in height, there is approximately a 400–450 kcal d\(^{-1}\) change in REE. A taller subject would thus have a higher REE and TEE than a shorter subject. We can estimate that 2.54-cm (1-inch) increments in height are accompanied by roughly 10 and 20 kcal d\(^{-1}\) differences in REE and TEE, depending on sex respectively. With an extra 12.7 cm (5 inches) in height, our
subject could eat about one more apple per day but her BMI would be 18.1 kg m$^{-2}$, just below the healthy range.

The additional energy expenditure with added height, independent of weight, is related to the proportion of body weight as metabolically active tissue. With added structural skeleton, skeletal muscle and related organs, a taller subject of equivalent weight to a shorter subject would have a higher proportion of weight as metabolically active tissues and a smaller proportion as low metabolic rate adipose tissue mass.

If I was older?

Our hypothetical subject is a young adult. If she was older, would the energy intake for weight maintenance be different even if her weight, height and activity level were the same? As shown in Fig. 3, with each decade increase in age, the energy requirement for weight maintenance is lower. Otherwise comparable 50- and 70-year-old women would not require 2372 kcal d$^{-1}$ as would our 20-year-old subject, but rather 2153 ($-9.2\%$) and 2007 ($-15.4\%$) kcal d$^{-1}$ respectively. As shown in the figure, a corresponding lower REE primarily accounts for the lower TEE and thus energy intake required for weight maintenance with greater age. These age-related differences would be even larger if the older women were sedentary or had a low active PA.

We can again translate these differences to foods eaten. The 50-year-old subject would be able to eat two and not four apples (i.e. one and not two donuts) to maintain the same weight as the 20-year-olds; and the 70-year-olds would not be able to eat any of the apples or donuts to maintain the same weight as her 20-year-old counterpart.

Why is REE lower in older compared with younger subjects? As one ages beginning in the early adult years, there is a progressive decline in metabolically active tissues relative to body weight (25). Thus, for the same body mass, an older subject usually has more fat and less lean tissue than their younger counterparts (25). Fat-containing adipose tissue has a very low metabolic rate compared with most lean tissues (26). All lean tissues tend to decline in mass with age, notably skeletal muscle and bone, even without a corresponding reduction in PALs. Energy is expended by the cellular component of lean tissues, and cell mass in adults declines with age and corresponds to the age-related decline in REE (27). Cellular energetic processes may also be involved in the lowering of REE with age (28). Lean tissue loss in the elderly is compounded by reduced levels of PA and the presence of chronic illnesses.

If I had the requirements of a man?

What if our demonstration subject was a man rather than a woman? Would there be a difference in energy requirements even at the same weight, height, age and activity level? If we again apply the appropriate equation in Table 4, we find that a man would maintain his weight at an intake of 2708 kcal d$^{-1}$ compared with the 2372 kcal d$^{-1}$ for the woman, a difference of 14.2%. The man can thus eat ~3 more apples (1.5 donuts) to maintain the same weight and activity level as the woman. Over the course of a year, the man would eat an extra 1226 apples or 613 donuts to maintain the same weight as the woman.

Men can eat more than women of comparable body size and activity level because men have a larger fraction of their weight as metabolically active tissue, notably skeletal muscle and body cell mass (29). The fraction of body mass in women as low-metabolic rate adipose tissue is correspondingly larger than it is in men.

Thus, the NAS/IOM prediction formulas provide an estimate of the magnitude of variation in population energy requirements as a function of activity level, weight, height, age and sex. Figure 4 summarizes how subjects differing in activity level, BMI, age and sex from our reference female would vary in predicted energy requirements for weight maintenance over the course of 1 year.

Longitudinal application of energy expenditure prediction equations

Up to this point, our examples are limited to cross-sectional estimates emerging from ‘what if?’ questions. Our rough estimates are applicable to subject groups and are not intended to provide individual food intake prescriptions. The NAS/IOM prediction formulas were developed on a cross-sectional sample of healthy children and adults (24). Insufficient data are currently available to develop comparable longitudinal prediction formulas. However, the same general phenomena would likely apply in a longitudinally evaluated population, including a higher energy requirement with an increase in PA or body mass and a decline in energy requirements, independent of weight and activity.
How much may I eat?

by increasing TEE from 2372 kcal d$^{-1}$ can apply the NAS/IOM equation for females in Table 4. We can cautiously apply the NAS/IOM equations for aging and weight gain. Generally, with an acute increase in energy intake, the available literature remains unsettled on if such a prediction might hold true in an individual subject. There are relatively few long-term (months or even years) overfeeding studies in the literature that were carried out under conditions of close observation and with well-defined PALs. Overfeeding in both humans and animals reportedly is accompanied by changes in thyroid hormones (33), sympathetic nervous system outflow (34), central nervous system counter-regulatory hormones (35), REE (36), components of non-REE (37) and other physiological adaptations that might limit weight gain as predicted. These adaptive responses may be genetically mediated (38,39).

The same estimation procedure applies when food intake is reduced by a specified amount. Obese subjects are often placed on a 500 kcal d$^{-1}$ deficit diet to achieve a lower healthier body weight. If we consider the morbidly obese woman presented earlier with BMI 40 kg m$^{-2}$, her baseline calculated energy intake is 3068 kcal d$^{-1}$ with a weight of 105.7 kg (232.5 pounds). What will her weight be if her intake is 500 kcal d$^{-1}$ less (i.e. 2568 kcal d$^{-1}$)? Our calculations show that this level of energy intake is required to support a weight of 69.5 kg (153 pounds), 36.2 kg (80 pounds) or 34% less than the baseline weight.

Based on the energy balance protocol. Large differences in the amount of weight loss were observed even though the magnitude of energy deficit was similar across all subjects; and weight effects were more similar within than between identical twin pairs.

REE may decline with underfeeding, even beyond that accounted for by the loss of body mass and metabolically active tissue (41,42). The ‘reduced’ obese may therefore have a lower REE than predicted for comparable weight stable adults (41). Although some studies show a ‘low’ metabolic rate in the reduced obese (41,42), the majority indicate similar values for predicted and measured REE (e.g. 43,44), measured during weight stability. Weight loss reportedly also has effects on non-REE components of energy expenditure (37,41,42).

While these remain topics of current scientific inquiry and debate, the important observation in the context of this review is that these prevailing controversies should be kept in mind when examining longitudinal questions using the NAS/IOM and other prediction equations. Changing energy intake by a specified amount, even under controlled...
feeding conditions, may thus not lead to a corresponding weight change as predicted by the NAS/IOM or FAO/WHO/UNU equations in an individual subject. The implication is that even if a subject were to avidly comply with our suggestion for energy intake or exercise level, the outcome in terms of weight change over the long-term is likely not predictable with high accuracy. This proviso must be kept in mind when we answer the ‘How much may I eat’ question as presented in the next section.

Answering the question ‘How much may I eat?’

How much may I eat if my weight is 90.9 kg (200 pounds) and I would like to have a normal weight? Answering this question requires consideration of the interpretation factors discussed in the previous sections. We can assume that the subject is a 35-year-old woman with a height of 1.68 m (5’6”) and a BMI of 32.4 kg m⁻². Her activity level is low active and ideally her BMI should be in the pre-defined ‘healthy’ range of 18.5–24.9 kg m⁻². Using the NAS/IOM equation provides an estimated current intake of 2523 kcal d⁻¹ and respective intakes of 2264 and 2328 kcal d⁻¹ for the normal BMI range of 18.5–24.9 kg m⁻². Lowering her intake by ∼200–300 kcal d⁻¹, with all of the aforementioned provisos, would lead to gradual weight loss over time and ultimately to a BMI within the desired range. A larger energy deficit will lead to a greater rate of weight loss, but the key is to maintain ∼200–300 kcal d⁻¹ deficit in the reduced state. What if the patient increased her PA to the ‘active’ level? She would not need to reduce her intake at all to reach a BMI of 24.9 kg m⁻² and her PAL would increase from 1.58 to 1.75. Examples such as these can be created with varying levels of age and PA. Keep in mind that these estimates are intended for groups and that individuals may differ widely in their responses; and that accuracy of TEE predictions in the post-obese state are still the subject of debate.

Qualitatively similar results are provided for REE and TEE by both the FAO/WHO/UNU and NAS/IOM equations. The REE results are also similar to those provided by the classic Harris–Benedict equation (14,15). There are four activity levels in the NAS/IOM equations compared with three in the FAO/WHO/UNU equations. Also, height is not considered a predictor variable in the FAO/WHO/UNU equations. Both equations were developed as a means of predicting group energy requirements and their application for individuals in this review is provided in an educational context. Neither equation considers race in predicting TEE and REE. However, there is substantial evidence now that adult African Americans have a lower REE (∼100 kcal d⁻¹) than Caucasians of similar weight, height and age (45). Recent data in African American and Caucasian children are showing similar trends (46). The question of race differences in REE and body composition is an evolving area as measurement methods become widely available. Similarly, both environmental temperature and altitude may have effects on energy requirements (24). Although one equation may be more accurate than the other, the most important consideration is that the strengths, limitations and appropriate applications of these TEE prediction formulas are understood by practitioners.

Summary and conclusions

The ‘calorie’ is increasingly a component of dialogue in classrooms, in the media and in the medical setting. However, outside of most nutritional professionals, knowledge of how to estimate energy requirements for weight maintenance is limited. In this review, we provide a general overview of how ‘actual’ energy expenditure and thus intake is accurately measured with doubly labelled water in subjects living within their natural environments. We then show how the doubly labelled water estimates were used to develop practical TEE prediction formulas based on a subject’s weight, height, age, activity level and sex. The corresponding factorial FAO/WHO/UNU equations are also provided. Optimally, both sets of prediction equations are suited for group TEE estimates. We have also shown their utility for educational purposes and our presentation emphasizes the potential methodologic limitations and interpretation issues when applied to longitudinal predictions. This information should provide the healthcare professional with the tools and understanding to appropriately answer the question, ‘How much may I eat?’

Conflict of Interest Statement

No conflict of interest was declared.

References


