Activity Diary Method for Predicting Energy Expenditure as Evaluated by a Whole-Body Indirect Human Calorimeter

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Summary In comparison with the energy expenditure determined by a whole-body indirect human calorimeter, which provides 24-h energy expenditure (TEE) with high precision and accuracy, the accuracy of predicting energy expenditure (EE) using an activity diary (AD) method was evaluated. Observed and predicted basal metabolic rate (BMR) as well as literature values for typical physical activities were used for TEE prediction. The effect of the number of recorded items in the activity diary on the accuracy of TEE was also examined. Additionally, predicted EE was divided into sleeping, exercise, and sedentary EE to evaluate the estimation errors in the AD method. Subjects were 20- to 69-y-old Japanese women (n=20) and men (n=21). Predicted TEE based on the AD was derived by applying the observed or predicted BMR to literature values for physical activities; i.e., relative metabolic rate (R.M.R.), physical activity ratio (PAR), and metabolic equivalent (MET). The BMR value observed for each subject was obtained by indirect calorimetry using a Douglas bag. The BMR for the subject was also estimated from the predictive equations in the 6th revision of the Recommended Dietary Allowances for the Japanese (1999). The correlations between observed and predicted TEE appeared stronger when using observed BMR than those using predicted BMR. Although the difference of mean values between the predicted and observed TEE was small, the limits of agreement between the predicted and observed TEE were around ±400 kcal. Predicted EE, excluding the time periods for exercise and rest laying down when determining BMR, showed similar results to those of TEE. Furthermore, the number of recorded items in the AD was not significantly correlated to the accuracy of the predicted TEE (r=-0.03). These findings indicate that the predicted TEE of the AD using observed or predicted BMR and literature values is favorably comparable to observed TEE using a whole-body human calorimeter on a group basis; however, its use as a proxy measure of TEE or EE on an individual basis may be limited.

Key Words whole-body indirect human calorimeter, energy expenditure, activity diary, basal metabolic rate, relative metabolic rate.

The activity diary (AD) method is widely used for calculating energy expenditure (EE) because, unlike the heart-rate method and other methods that require attaching instruments to the subjects, it does not require a special measurement instrument for predicting EE (1). The prediction error when using an AD has been assessed by examining the relationship between the observed total energy expenditure (TEE) determined by the DLW method and the predicted TEE determined by the AD. The main sources for the differences between the observed and predicted TEE values are derived from the basal metabolic rate (BMR) and literature values for physical activities. Previous studies reported that the accuracy of the AD increased when the observed BMR was used (2, 3). Morio et al. (4) noted that, although the factorial method gives satisfactory estimates of individual TEE when the observed EE data for each physical activity on an individual basis are used, it depends on the subject’s cooperation regarding activity reporting. However, in the case of the AD method, the BMR and EE for each physical activity are rarely actually measured. The usual procedure is that either the predicted or measured BMR is used and literature values for physical activities are applied for predicting EE.

Several types of literature values are currently used for predicting TEE or EE. In Japan, the relative metabolic rate (R.M.R.) for typical physical activities compiled and reported by Numajiri (5) is frequently used as for the literature values. However, there is a concern about the use of R.M.R. obtained during 1950–1960 because it may not correspond to current lifestyles (6). The literature values for physical activities such as physical activity ratio (PAR) (7) and metabolic equivalent (MET) (8)
have been used in other countries. But the validity of applying these literature values to Japanese is unknown since most of the original data were obtained from non-Japanese subjects.

The different manner of recording the AD may be another source of errors in predicting EE. For example, one study uses a formatted sheet that requires subjects to record the major physical activity by themselves every 15 min during a 24 h period. Another study uses a form of AD that asks subjects to record their activities minute by minute, i.e., the time at the beginning of each type of physical activity. Only a limited number of reports have examined the validity of the AD in estimating TEE using the whole-body indirect human calorimeter (IHC) (9, 10), and the accuracy of these methods remains unknown.

The major objective of the present study is to evaluate the accuracy of predicted TEE and EE (during sleep, exercise, and sedentary time periods) using the AD method, focusing on the effects of difference in the use of BMR values and literature values for typical physical activities. Our focus is also directed to whether detailed recording in the AD contributes to improving the accuracy of predicted TEE and EE. This type of evaluation becomes possible only by comparing the predicted TEE or EE with the simultaneous measurement of reliable TEE and EE of a subject. As a reference value, we used the TEE and EE determined by the IHC, which provides EE values with the highest precision and accuracy among currently available indirect calorimetric equipments (11).

METHODS

Subjects. The subjects were 20- to 69-y-old Japanese women (n=20, 32±10 y) and men (n=21, 30±11 y). All of the subjects were in good health, without abnormalities affecting the EE such as abnormal thyroid gland function. Female subjects were interviewed regarding phase of menstrual cycle. Body height and weight were measured to the nearest 0.1 cm and 0.1 kg, respectively. Informed consent was obtained and the Ethical Committee of the National Institute of Health and Nutrition of Japan approved the study protocol.

Measurement items and methods. EE was determined using the IHC and was also predicted by the AD with observed or predicted BMR and literature values for physical activities.

As we have previously reported in details on the system of IHC constructed at the National Institute of Health and Nutrition in Japan regarding the diagram and its measurement accuracy (12), the following is a brief description of the IHC. The temperature and relative humidity in the room are controlled by an air conditioner at constant values of 25°C and 55%, respectively. VO2 is determined by the flow rate exhausted from the IHC and the O2 concentrations of the inlet and outlet air of the IHC. VCO2 is also determined by the same procedure as VO2. The values of VO2 and VCO2 are expressed under the conditions of standard temperature, pressure and dry (STPD). EE is estimated from VO2 and VCO2 using Weir’s equation (13). Futami et al. (12) repeatedly performed ethanol combustion experiments from 30 min to 6 h to evaluate the accuracy and precision of the EE measured by the IHC. As reported by Futami et al. (12), the accuracy and precision of our IHC for measuring energy expenditure expressed as a mean percentage difference and coefficient of variation (CV%) were +0.9% and ±1.9%, respectively.

EE measurement of the subject in the IHC started at 18:15 on the first day. The TEE and EE during the three categories of time-period (sleeping, 8 h; exercise, 135 min; sedentary time excluding rest laying down in the early morning, 13 h and 15 min) were calculated. During the stay in the IHC, the subject was asked to follow a simple experimental protocol, which was prepared to simulate the typical lifestyle of a sedentary Japanese based on the results from a nationwide time allocation survey (i.e., time spent commuting, sleeping, eating meals, etc.) (14). In short, the subjects followed a standardized activity program that included three meals, sleeping time (8 h), four 15-min periods of exercise on a stationary cycle ergometer, followed by four 15-min periods of standing (a total of 120 min), and a 15-min period of exercise by performing step-ups (15 step-ups/min on 20-cm-high blocks). The exercise intensities of cycling were 45 W (morning) and 35 W (evening) for males and 40 W (morning) and 30 W (evening) for females. These levels of intensity were set, according to the ACSM’s metabolic equations (15), to simulate energy expended daily by brisk walking in the morning and relatively slow walking in the evening for commuting to and from home. During the other time periods, subjects were only permitted to engage in light activities such as washing, dressing, undressing, viewing television, writing, etc. Subjects were asked to refrain from sleeping and high-intensity exercise during these time periods.

The observed BMR was determined at 07:00 on the third day. The subject was quietly awakened and a face-mask connected to a Douglas bag was attached while the subject remained in bed. The measurements for oxygen consumption were made 35–45 and 46–56 min after waking. The volume of expired air was measured with a certified dry gas meter (SHINAGAWA DC-5, Tokyo, Japan). Expired air was sampled and the O2 and CO2 concentrations were measured using a mass spectrometer (ARCO SYSTEM, ARCO-1000, Kashiwa, Japan). For each experiment, the gas analyzer was initially calibrated using a certified gas mixture and atmospheric air. The BMR value for each subject was also predicted from the sex, age and weight using the equations in the 6th Revision of the Recommended Dietary Allowances for the Japanese (RDA-Jpn) (16). In most of the previous studies, on which the Japanese BMR standard was based, BMR was measured using the following method: the subjects were requested to report under post-absorptive conditions to the laboratory in the early morning and to rest quietly laying on their back for at least 30 min (17). Although in previous studies, it was
recommended that the room temperature be controlled within 18–25°C as a rule, some data were not within this range of room temperature (17, 18). In the present study, the room temperature was maintained at 25°C, and BMR was measured without walking after waking.

EE was predicted using the AD in combination with the observed or predicted BMR and three kinds of literature values for physical activities: R.M.R., PAR, and MET. We used a form of AD that asks a subject to record the time at the beginning of each type of physical activity, and the number of specified activities recorded in the AD may vary from one subject to another. The prediction equations for physical activity EE were as follows: 1) EE=(R.M.R.×BMR)+1.2×BMR (=estimate of resting metabolic rate), 2) EE=(PAR×BMR), 3) EE= resting metabolic rate×METs/min, and 4) EE=(3.5×body weight×METs)×5/1,000. The resting metabolic rate was estimated multiplying BMR by 1.2. The predicted EE by AD was calculated by applying the reference values.

**Statistics.** Statistical analyses were performed with StatView for Windows (version 5; SAS Institute Inc., Cary, NC, USA). All results are shown as mean ± standard deviation (SD). The relationship between the observed and predicted values was evaluated by Pearson’s correlation. The percent difference was calculated as (predicted value−observed value)/observed value×100. The square root of the mean of the squared deviations of predicted minus measured observations (total error) was also calculated in order to assess the resulting error. Agreement of EE or TEE between the AD method and IHC was further examined by plotting the difference in the predicted values against the mean with limits of agreement (mean difference ±2SD of the differences; the 95% limits of agreement, which gives an indication of the precision of the method) as suggested by Bland and Altman (19). Comparisons of the EE/BMR ratio in three categories of activity and the effects of the number of recorded items on TEE prediction by R.M.R. were tested by one-way analysis of variance. A post hoc test was performed using the Scheffe’s test. All statistical tests were regarded as significant when the probabil-

| Variables | Females (n=20) | Males (n=21) | All subjects |
|-----------|----------------|--------------|--------------|
| Height (cm) | 159.8±4.8 | 173.6±6.6 | 166.8±9.0 |
| Weight (kg) | 53.2±6.1 | 70.5±12.6 | 62.1±13.2 |
| BMI (kg/m²) | 20.8±1.9 | 23.3±3.0 | 22.1±2.8 |
| Predicted basal metabolic rate (kcal/d) | 1203±145 | 1648±262 | 1431±308 |
| Observed basal metabolic rate (kcal/d) | 1155±123 | 1586±257 | 1376±297 |

1 BMR prediction equation in the Recommended Dietary Allowances for the Japanese, 6th Revision (1999).
There were a significant correlation and a difference between observed and predicted basal metabolic rate (r=0.92, p<0.01 and p<0.01, respectively).

Table 2-1. Summary of the statistical analyses on the differences between the predicted and observed total energy expenditure.

| Predicted TEE and observed TEE | Mean±SD (kcal/d) | Mean difference (kcal/d) | Total error (kcal) | R² | Mean difference Females (kcal/d) | Males (kcal/d) |
|-------------------------------|-----------------|-------------------------|--------------------|----|---------------------------------|----------------|
| Relative metabolic rate       |                 |                         |                    |    |                                 |                |
| Predicted TEE (Observed BMR)  | 2.02±440*       | -42±166                 | 169                | 0.861*** | -66±124                        | -20±198        |
| Predicted TEE (Predicted BMR) | 2.10±462        | 39±226                  | 226                | 0.765*** | 6±183                          | 71±261         |
| Observed TEE                  | 2.06±373        |                         |                    |    |                                 |                |
| Physical activity ratio       |                 |                         |                    |    |                                 |                |
| Predicted TEE (Observed BMR)  | 2.09±415        | 31±175                  | 176                | 0.818*** | 41±151                         | 22±198         |
| Predicted TEE (Predicted BMR) | 2.17±433**      | 115±224                 | 249                | 0.733*** | 117±203                        | 113±248        |
| Observed TEE                  | 2.06±373        |                         |                    |    |                                 |                |
| Metabolic equivalent          |                 |                         |                    |    |                                 |                |
| Predicted TEE (Observed BMR)  | 2.12±453        | 56±181                  | 187                | 0.847*** | 38±128                         | 74±221         |
| Predicted TEE (Predicted BMR) | 2.01±432        | -53±225                 | 229                | 0.729*** | -17±161                        | -87±272        |
| Observed TEE                  | 2.06±373        |                         |                    |    |                                 |                |

TEE: total energy expenditure, BMR: basal metabolic rate.

* ** Significantly different between observed and predicted TEE, *p<0.05, ** p<0.01.

*** Statistically significant, p<0.001.
No significant sex difference was observed for any of the mean differences.
RESULTS

The physical characteristics and observed and predicted BMR of subjects are shown in Table 1. For all subjects, the relationship between the observed and predicted BMR demonstrated a strong correlation ($r=0.92$, $p<0.01$). However, the predicted value was significantly larger than the observed value (4.4–9.8%, $p<0.01$). The mean difference in BMR was 55 kcal. The 95% confidence interval of estimated error in BMR was ±244 kcal. No significant difference in BMR of female subjects was detected in terms of phase of the menstrual cycle.

The details of analyses on the observed and predicted values for TEE are shown in Table 2-1, and those for EE (excluding the time periods for exercise and rest laying down at the BMR measurement) in Table 2-2. No significant effect of sex was observed for the differences between predicted and observed values for TEE or ER. Therefore, the following description is the result for all subjects. The relationship between the observed and predicted TEE derived from the observed BMR exhibited a stronger correlation than that from the predicted BMR. The mean differences in TEE resulting from the use of observed and predicted BMR were –42 kcal and 39 kcal with the use of R.M.R., 31 kcal and 115 kcal with PAR, and 56 kcal and –53 kcal with MET, respectively. The results for EE, excluding the time periods for exercise and rest laying down for BMR determination, showed a similar tendency to the predicted TEE (Table 2-2). The total error for the TEE and EE excluding exercise and rest laying down using the observed BMR demonstrated lower values than those using predicted BMR from every type of literature value (Table 2-1, -2).

The 95% confidence intervals of the estimated error in TEE using the observed and predicted BMR were ±331 kcal and ±451 kcal with the use of R.M.R. (Fig. 1-1, A and B), ±350 kcal and ±448 kcal with PAR (Fig. 1-2, A and B), and ±361 kcal and ±451 kcal with MET (Fig. 1-3, A and B), respectively.

Figure 2 shows the mean values of the EE/BMR ratio for three categories of activity, indicating different tendencies for the three kinds of literature values applied. First, regarding sleeping EE, MET significantly overestimated while R.M.R. significantly underestimated. Second, regarding exercise EE, PAR, and MET significantly underestimated. Finally, regarding EE of sedentary activity, no differences were observed by the three kinds of literature values.

Figure 3 shows the relationship between the number of recorded activity items and the error in TEE estimation, in which no significant correlation was observed ($r=-0.03$), suggesting that the prediction errors did not depend on the number of activity items recorded. The mean number of recorded activities was 74±22 times/24 h, and there was no difference between female and male subjects.

DISCUSSION

The predicted TEE using either the observed or predicted BMR was relatively comparable with the observed TEE, and the mean differences between the observed and predicted TEE were small. However, the agreement of the observed TEE with the predicted TEE using the observed BMR was higher than that with the predicted TEE using the predicted BMR. These results are similar to those of previous studies using the IHC or DLW methods (2, 10, 20).

One of the potential sources of difference in TEE pre-
Fig. 1. Limits of agreement between predicted and observed total energy expenditure. 1A: TEE predicted using observed BMR and relative metabolic rate (R.M.R.). 1B: TEE predicted using predicted BMR and relative metabolic rate (R.M.R.). 2A: TEE predicted using observed BMR and physical activity ratio (PAR). 2B: TEE predicted using predicted BMR and physical activity ratio (PAR). 3A: TEE predicted using observed BMR and metabolic equivalent (MET). Prediction of energy expenditure of the specified activity was made by assuming the resting metabolic rate being observed BMR × 1.2 and applying it to the MET value. 3B: TEE predicted using predicted BMR and metabolic equivalent (MET). Prediction of energy expenditure of the specified activity was made by assuming the resting metabolic rate as 3.5 ml O₂/kg/min and applying it to the MET value. Difference: predicted total energy expenditure–observed total energy expenditure, BMR: basal metabolic rate, TEE: total energy expenditure.
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Fig. 2. Comparison of predicted EE/BMR ratio for three categories of activity.

Fig. 3. Predicted difference in total energy expenditure against the number of items recorded in the activity diary. Predicted total energy expenditure was obtained using observed BMR and relative metabolic rate (R.M.R.). Difference: predicted total energy expenditure—observed total energy expenditure.

Prediction is the BMR data used. A particularly important point is the conditions for BMR determination. In the present study, the observed BMR was determined 35 min after awakening. Kashiwazaki et al. (21) reported that an increased post-absorptive resting metabolic rate was observed after a 10-min walk as compared to the resting metabolic rate taken after waking and remaining inactive. BMR in the present study was measured with little ambulation after awakening, while in most BMR studies, on which the present Jpn-RDA BMR standards are based, the subjects were measured after reporting themselves to the laboratory in the morning. The difference in room temperature is also likely to result in differences in BMR determination, even though it is within the range of a comfortable ambient temperature (21). In the present study, the indoor temperature during BMR measurement was maintained at 25°C. In previous studies made in the 1950–60s, the room temperature was recommended to be within 18–25°C. However, some of the previous studies could not afford to keep the temperature within this range during the summer and winter seasons, or simply did not report the room temperature (17, 18). Kashiwazaki et al. (21) showed that although the post-absorptive resting metabolic rate at an indoor temperature of 20°C has a seasonal difference, the post-absorptive resting metabolic rate at 25°C does not substantially differ in any season. The reason why our predicted BMR overestimates the observed BMR by 4.4% (mean difference, 55 kcal; 95% confidence interval, ±244 kcal) is partially explained by the measurement conditions under which BMR was determined. Another important source of the difference is that the RDA-Jpn equation gives a constant coefficient for body weight according to gender and age. In the method of multiplying the constant value by body weight, the prediction error increases as body fat increases. If an individual is overweight or underweight, the prediction error for BMR may result in an error in TEE (18).

There are other potential sources of TEE prediction error. We have initially assumed that the prediction error of TEE may differ depending on the kinds of literature values expressed in different forms. In Japan, R.M.R. has been used mainly in the field of occupational health as the intensity index of occupational activity (5). PAR has recently been used mainly in the area of nutrition to evaluate the energy demand for leisure time and occupational activities (22). MET has been initially used as the index of exercise intensity, and MET values were subsequently developed for use in occupational and leisure time activities (23). Despite their different forms and backgrounds, the ability of predicting TEE as a group mean with these values was comparable. However, the range of error in the predicted EE or TEE on an individual basis was large enough for practical use.

We also examined the mean differences of the EE/BMR ratio between those observed by the IHC and those predicted by the AD using each type of literature value for three categories of activity (i.e., sleeping, sedentary,
and exercise), Geissler et al. (9) noted an overestimation of \(17 \pm 16\%\) using the BMR predicted from the Harris-Benedict equation. Although the mean predicted error of sleeping time in the present study was smaller than that found by Geissler et al. (9), the use of MET significantly underestimated the sleeping EE/BMR ratio \((p<0.01)\), and the use of R.M.R. significantly underestimated it \((p=0.04)\). During exercise time, PAR and MET significantly underestimated the ratio \((p<0.01, p<0.01)\). The difference between the predicted and observed EE may not be surprising because the literature values do not always represent the actual exercise intensity. In contrast, the predicted and observed EE/BMR ratios were not significantly different from each other when any type of literature value (R.M.R., PAR or MET) was used to predict sedentary EE.

The AD method generally ignores the variability between individuals because it uses literature values without considering the body composition \((5, 24)\). The EE for fidgeting and maintaining posture, which differs from exercise under experimental conditions, has been recognized as one of the reasons for the inter-individual difference of TEE \((24-28)\). While literature indicates constant values for particular physical activities, some of the physical activities in the IHC may have been performed variably and intermittently. The measurement error of BMR is also an important factor that influences the accuracy of TEE. These and other factors that are not possible to describe in the records of the AD have contributed to errors in predicting EE or TEE, particularly on the individual basis.

In conclusion, this study indicates that the TEE predicted by the AD method using observed or predicted BMR and literature values is favorably comparable to observed TEE using a whole-body human calorimeter on a group basis; however, its use as a proxy measure of TEE or EE on an individual basis may be limited when an individual or a group mean TEE is predicted using questionnaires such as the AD and literature values do not always represent the actual exercise intensity. In contrast, the predicted and observed EE/BMR ratios were not significantly different from each other when any type of literature value (R.M.R., PAR or MET) was used to predict sedentary EE.

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