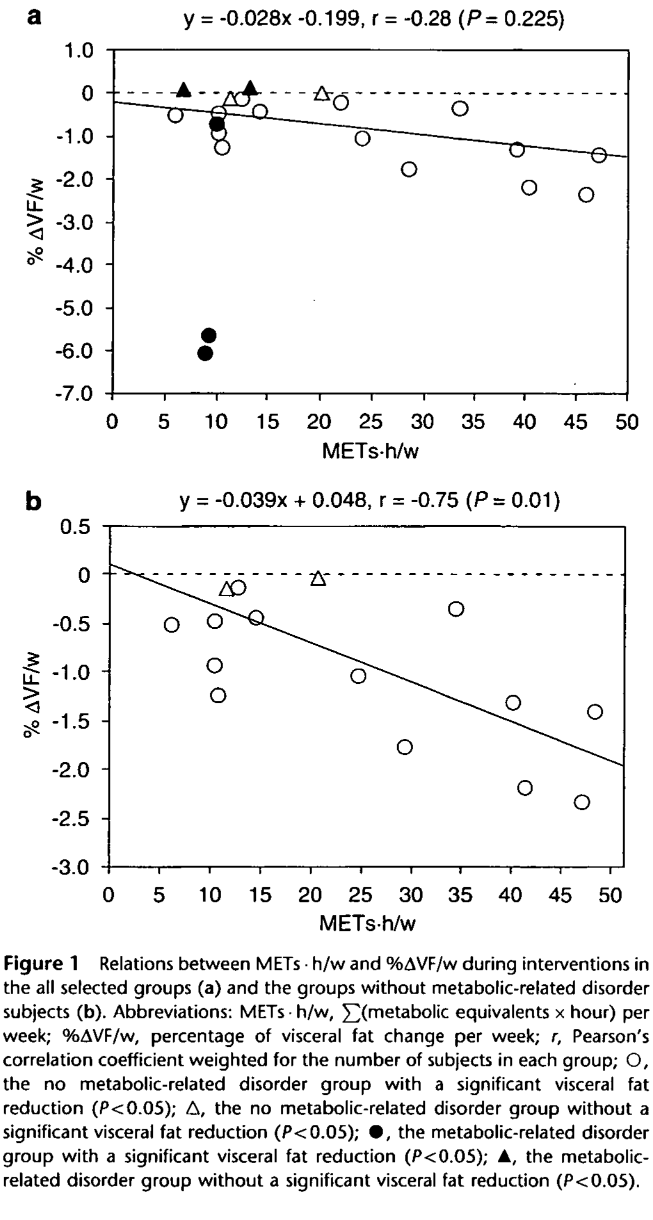


**Figure 1** Relations between METs · h/w and %ΔVF/w during interventions in the all selected groups (a) and the groups without metabolic-related disorder subjects (b). Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; %ΔVF/w, percentage of visceral fat change per week; *r*, Pearson's correlation coefficient weighted for the number of subjects in each group; ○, the no metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); △, the no metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$); ●, the metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); ▲, the metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$).

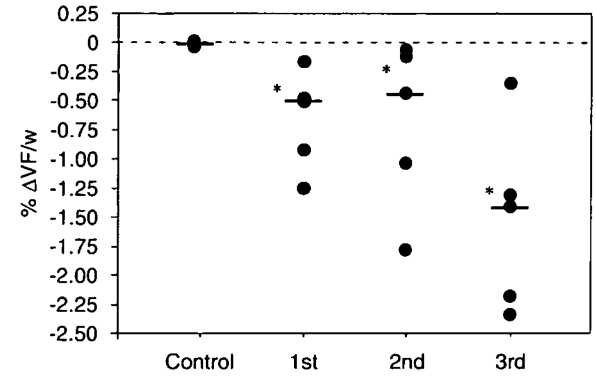


**Figure 2** Comparison of mean %ΔVF/w between a control group and exercise groups divided into tertiles by METs · h/w amount in the groups without metabolic-related disorder groups. Ranges of METs · h/w in each categorized group were 5.9–11.4 (1st), 12.3–28.5 (2nd), 33.4–47.1 (3rd). Side bar means median in each group. Statistically significant difference between the groups were observed ($P=0.003$). * A significant difference was found in comparison with the control group using the *post hoc* test ($P<0.05$). Abbreviations: %ΔVF/w, percentage of visceral fat change per week; METs · h/w, ∑(metabolic equivalents × hour) per week.

physical activity and total or regional fat reduction. As a result, even though some literatures were added for the analysis, whether physical activity was associated with reductions in abdominal fat in a dose–response manner was still unclear. Kay and Fiatarone Singh[10] also reviewed the beneficial influence of physical activity on visceral fat reduction, but dose–response data were not examined. These previous reviews did not include studies involving large amounts of exercise. In our analysis, some additional studies, especially three studies with values of 35 METs · h/w or more,[21,22,29] were included in addition to papers used by previously published reviews. Furthermore, the amount of aerobic exercise undertaken during the intervention was expressed as METs · h/w, because METs · h could adjust the EE for each subject's weight. As a result, there was no relationship between METs · h/w and %ΔVF in the 21 groups from 16 studies including the metabolic-related disorder subjects. However, in subjects without metabolic-related disorders, we found a dose–response relationship between aerobic exercise and visceral fat reduction. Indeed, if obese subjects without metabolic-related disorders practiced aerobic exercise, the degree of visceral fat reduction could be directly attributed to the aerobic exercise amount. For example, if an obese person without metabolic-related disorders tries to reduce 10% of his VF amount in 10 weeks, instructors should prescribe about 27 METs · h/w, because 27 METs · h/w corresponds to 1% of ΔVF/w. Thus, our findings could be used to affect decisions on the amount of aerobic exercise recommended for visceral fat reduction in obese people.

In the selected studies, six groups from four studies consisted of metabolic-related disorder subjects. Results from the metabolic-related disorder subjects were contradictory. Two groups with type 2 diabetes[9,38] clearly exhibited a significant visceral fat reduction, although these results may have been exaggerated by the shortest-term intervention (8 weeks) in the selected studies. Two groups with dyslipidemia[24] did not significantly reduce visceral fat, while the group with type 2 diabetes reported by Giannopoulou *et al.*[16] was close to the regression line for identifying a dose–response relationship. Kelly and Simoneau[39] showed that the capacity of fat oxidation during aerobic exercise in individuals with type 2 diabetes was lower than that for healthy individuals. However, several other investigators did not find any significant difference in fat oxidation capacity between subjects with or without type 2 diabetes.[40,41] Furthermore, Raguso *et al.*[42] observed that fat oxidation during aerobic exercise in the group with type 1 diabetes was higher than that of the control group. These studies were conducted

Table 3 Mean METs · h/w and %ΔVF/w, and correlate coefficients between METs · h/w and %ΔVF/w during interventions in the groups categorized by intervention duration or gender

| Groups | Intervention duration | | Gender | |
|---|---|---|---|---|
| | ⩽16 week | >16 week | Women only | Men only |
| *From all the selected groups* | | | | |
| Number of groups | 10 | 11 | 7 | 6 |
| Number of subjects | 183 | 399 | 168 | 98 |
| METs · h/w | 23.5±17.1 | 17.1±9.1 | 23.1±13.0 | 27.6±17.7 |
| %ΔVF/week | −2.22±2.00 | −0.41±0.55 | −0.90±0.86 | −1.83±1.98 |
| r (P value) | −0.06 (0.877) | −0.34 (0.302) | −0.89 (0.007) | −0.05 (0.931) |
| *From the groups without metabolic-related disordered subjects* | | | | |
| Number of groups | 7 | 8 | 6 | 5 |
| Number of subjects | 154 | 271 | 157 | 90 |
| METs · h/w | 29.5±17.2 | 18.2±9.8 | 25.3±12.7 | 31.3±17.1 |
| %ΔVF/w | −1.40±0.67 | −0.55±0.58 | −0.93±0.94 | −1.07±0.73 |
| r (P value) | −0.81 (0.027) | −0.36 (0.378) | −0.93 (0.008) | −0.71 (0.184) |

Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; r, Pearson's correlate coefficient; %ΔVF/w, percentage of visceral fat change per week. r values were weighted for the number of subjects in each group.

under conditions where the subjects with or without diabetes had fasted.[39–42] Thus, visceral fat reduction in the metabolic-related disorder subjects could be due to more complex mechanisms. Therefore, formulation of a dose–response relationship between aerobic exercise and visceral fat reduction has to take into account the separation of subjects with and without metabolic-related disorders.

### *How much exercise is needed for significant visceral fat reduction?*

It is important to suggest a lower limit for the quantity of aerobic exercise required for significant visceral fat reduction. In our selected groups, METs · h/w values ranged from 5.9 to 47.1. Except for the lowest METs · h/w obtained from Miyatake *et al.*[20] in which the subjects were instructed to increase the number of steps walked every day for 1 year, significant visceral fat reduction was observed from about 10 METs · h/w.[16,18,25] Thus, at least 10 METs · h/w is required for significant visceral fat reduction by aerobic exercise, such as brisk walking, light jogging or stationary ergometer usage. For the purpose of weight or body fat loss, the American College of Sports Medicine (ACSM) recommends obese individuals to engage in moderately intense physical activity for minimum 150 min/w, and preferably more than 200–300 min/w.[43] The minimum value in this recommendation nearly equals to 10 METs · h/w when performing moderate physical activities such as brisk walking. In the present study, we divided the aerobic exercise groups into tertiles by their METs · h/w amount to determine the boundary of obvious visceral fat reduction. As a result, each exercise group category had a higher visceral fat reduction than the control group. However, there was no significant difference between %ΔVF/w values in the three exercise categories. This result may be due to an insufficient number of groups. The median of %ΔVF/w in the 3rd tertile exercise group was 40.2, which was much higher than that of the 1st and 2nd tertile exercise groups. That is to say, approximately 40 METs · h/w or more may be required to reduce visceral fat solely by aerobic exercise, such as brisk walking, light jogging or stationary ergometer usage. Forty METs · h/w equates to approximately 3780 kcal/w for a person with 90 kg body weight. Although this value is slightly lower than the ACSM's recommendation corresponding to a minimum 4500 kcal/w for combined exercise and diet with intakes of not lower than 1200 kcal/d, this results in an energy deficiency of approximately 500–1000 kcal/d, which could be hard for obese people with low physical fitness to practice continuously. Therefore, for an individual's prescription for visceral fat reduction, recommendations that balance diet and exercise should be examined in another research.

### *Influences of intervention duration or gender on the dose–response relationship*

Ross and Janssen[13] revealed that an increase in physical activity is positively associated with a reduction in total fat in a dose–response manner in short-term interventions (⩽16 week), but not in long-term interventions (⩽26 week). In the review by Kay and Fiatarone Singh,[10] there was no relation between change in abdominal fat and intervention duration. In the present study, EE by aerobic exercise was positively correlated with visceral fat reduction in the short-term (⩽16 wk) studies when the metabolic-related disorder groups were discounted. Ross and Janssen[13] suggested that in long-term exercise studies, it is difficult to complete a weight loss of an expected volume from expended energy consumption, although it is not clear which factors, such as the adherence to interventions, or over-reporting of exercise amount, influenced the results. Our results support this trend with

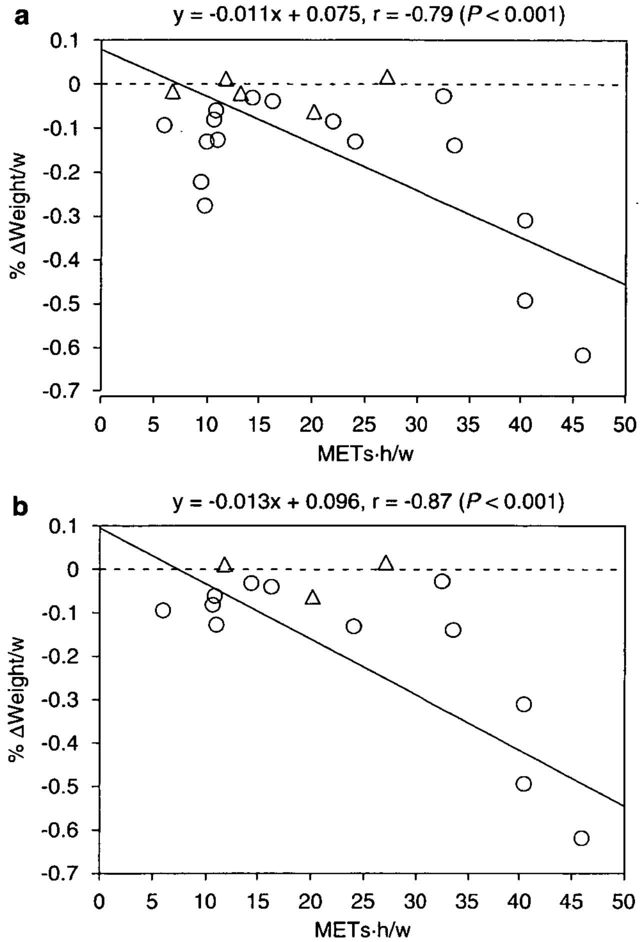


**Figure 3** Relations between METs · h/w and %ΔWeight/w during interventions in the all selected groups (**a**) and after excluding the groups with metabolic-related disorder subjects (**b**). Abbreviations: METs · h/w, ∑(metabolic equivalents × hour) per week; %ΔWeight/w, percentage of weight change per week; *r*, Pearson's correlate coefficient; ○, the group with a significant visceral fat reduction ($P<0.05$); △, the group without a significant visceral fat reduction ($P<0.05$). The groups without a weight loss intentionally were excluded for these analysis.

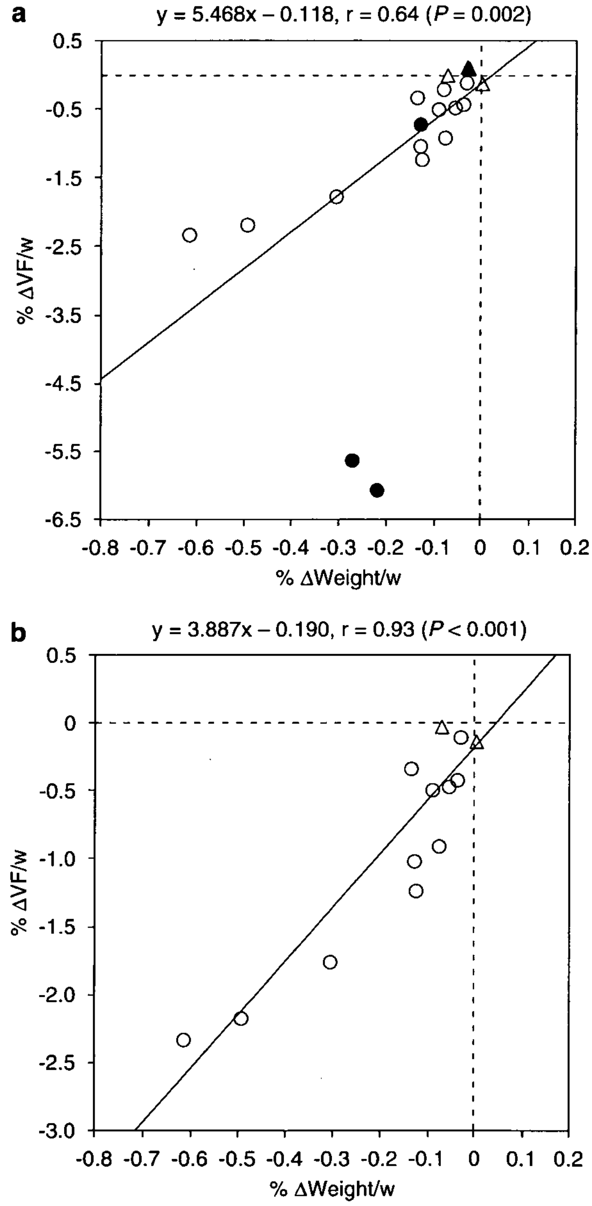


**Figure 4** Relations between %ΔVF/w and %ΔWeight/w during interventions in the all selected groups (**a**) and after excluding the groups with metabolic-related disorder subjects (**b**). Abbreviations: %ΔVF/w, percentage of visceral fat change per week; %ΔWeight/w, percentage of weight change per week; *r*, Pearson's correlation coefficient weighted for the number of subjects in each group; ○, the no metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); △, the no metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$); ●, the metabolic-related disorder group with a significant visceral fat reduction ($P<0.05$); ▲, the metabolic-related disorder group without a significant visceral fat reduction ($P<0.05$).

respect to visceral fat reduction. That is, if subjects can complete the instructed exercise volume, short-term interventions could be more efficient than long-term interventions for weekly visceral fat reduction. Generally, if participants do not quickly observe the benefits of a weight-loss program, their motivation for continuing the regimen is reduced.[44,45] Accordingly, for significant visceral fat reduction, obese people should initially practice a relatively high volume of aerobic exercise, which can then be reduced to a manageable amount that they can practice for the long term.

In the present study, a significant relationship between METs · h/w and %ΔVF was observed in women-only groups, with and without the metabolic-related disorder subjects, while there was no significant relationship in the men-only groups. The limited number of studies was insufficient to determine the influence of gender on the dose–response relationship. However, it is difficult to compare differences of the amount of visceral fat reduction by aerobic exercise between men and women, as women generally store a greater total fat mass relative to body weight than men.[46] Also, body fat distribution is different between men and women as men tend to have more central obesity than women.[47] Initial values of visceral fat could contribute to the amount of visceral fat lost during intervention. If these biases between men and women were excluded, that is, if the absolute amount of total and visceral fat were matched between men and women, then the relative obesity levels for each gender would be much different. It is likely that gender, as well as intervention duration, could be factors in the differences in rate of visceral fat reduction per week.

*Relationship between visceral fat reduction and weight reduction*
Weight reduction during interventions could be seen solely as the result of fat mass reduction, because fat-free mass reduction accounts for only a small part of weight reduction.[38] Visceral fat volume is about 10–20% of total fat volume[48,49] and reduction of the subcutaneous fat volume largely reflects weight reduction. In a limited number of selected studies, METs · h/w and %ΔWeight/w had a significant correlation in both the groups with and without metabolic-related disorders. Therefore, metabolic-related disorders, especially type 2 diabetes, may have a small impact on a dose-relation between weight loss and aerobic exercise during intervention compared to the amount of visceral fat reduction.

On the other hand, our results indicate a significant relationship between %ΔWeight/w and %ΔVF/w, especially in the subjects without metabolic-related disorders. We can say that %ΔVF/w corresponds to four to five times %ΔWeight/w when obese people practice aerobic exercise. However, previous studies suggest that visceral fat is used more quickly as an energy resource than subcutaneous fat during aerobic exercise-induced weight loss.[50] In our analysis, the intercept of the regression line between %ΔWeight/w and %ΔVF/w in the subjects without metabolic-related disorders was significantly different from zero. Although the trend showed that the more weight was lost, the more visceral fat was reduced, a significant reduction of visceral fat, which occupies less than 5% of body weight,[48,49] may also occur without a significant weight reduction with aerobic exercise. In fact, this phenomenon was reported by studies that examined whether or not visceral fat was reduced by aerobic exercise, if energy intake corresponding to the EE value by prescribed aerobic exercise was added to the baseline. Such an adjustment in the calculation did not lead to a significant weight reduction.[22,29] Generally, it is difficult for obese people to reduce weight largely by practicing exercise alone, compared to diet.[8] Therefore, exercise is inclined to be optional with a diet therapy for weight loss. However, even if insufficient weight loss does occurs, visceral fat could be reduced by doing aerobic exercise, a prescription supported by recent studies.[16,22] These results provide evidence of the usefulness of aerobic exercise for visceral fat reduction.

There are a number of limitations in the present study. The number of selected studies, especially those which measured EE for the prescribed exercises, were still insufficient for defining a clear aerobic exercise amount that resulted in significant visceral fat reduction. Additionally, the influence of several factors, such as metabolic-related disorders, gender and intervention duration, on visceral fat reduction remains unclear. Most of trials in the selected studies had applied brisk walking, light jogging and stationary ergometer, so whether or not other types of activities could lead to a similar result cannot be clarified from this study. Furthermore, while the present study investigated visceral fat reduction, studies with visceral fat gain should also be included in the analyses.

In conclusion, data collected from selected studies suggested that aerobic exercise as a weight loss intervention has a dose–response relationship with visceral fat reduction in obese subjects, excluding groups with metabolic-related disorders. Additionally, visceral fat reduction is significantly related to weight reduction during aerobic exercise intervention, although a significant visceral fat reduction may also occur without significant weight loss. Furthermore, for significant visceral fat reduction, at least 10 METs · h/w of aerobic exercise is required. However, since the number of selected studies was still insufficient, further studies are required.

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# Evaluation of Low-Intensity Physical Activity by Triaxial Accelerometry

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**Abstract**

MIDORIKAWA, TAISHI, SHIGEHO TANAKA, KAYOKO KANEKO, KAYO KOIZUMI, KAZUKO ISHIKAWA-TAKATA, JUN FUTAMI, AND IZUMI TABATA. Evaluation of low-intensity physical activity by triaxial accelerometry. *Obesity.* 2007;15:3031–3038.

***Objective:*** To develop regression-based equations that estimate physical activity ratios [energy expenditure (EE) per minute/sleeping metabolic rate] for low-to-moderate intensity activities using total acceleration obtained by triaxial accelerometry.

***Research Methods and Procedures:*** Twenty-one Japanese adults were fitted with a triaxial accelerometer while also in a whole-body human calorimeter for 22.5 hours. The protocol time was composed of sleep (8 hours), four structured activity periods totaling 4 hours (sitting, standing, housework, and walking on a treadmill at speeds of 71 and 95 m/min, 2 × 30 minutes for each activity), and residual time (10.5 hours). Acceleration data (milligausse) from the different periods and their relationship to physical activity ratio obtained from the human calorimeter allowed for the development of EE equations for each activity. The EE equations were validated on the residual times, and the percentage difference for the prediction errors was calculated as (predicted value − measured value)/measured value × 100.

***Results:*** Using data from triaxial accelerations and the ratio of horizontal to vertical accelerations, there was relatively high accuracy in identifying the four different periods of activity. The predicted EE (882 ± 150 kcal/10.5 hours) was strongly correlated with the actual EE measured by human calorimetry (846 ± 146 kcal/10.5 hours, $r = 0.94$ $p < 0.01$), although the predicted EE was slightly higher than the measured EE.

***Discussion:*** Triaxial accelerometry, when total, vertical, and horizontal accelerations are utilized, can effectively evaluate different types of activities and estimate EE for low-intensity physical activities associated with modern lifestyles.

**Key words: accelerometry, energy expenditure, indirect calorimetry, physical activity**

## Introduction

Activity thermogenesis can be separated into two components: exercise-related activity thermogenesis and non-exercise activity thermogenesis (NEAT)[1] (1). NEAT, composed mainly of the energy expenditure (EE) related to low-to-moderate intensity daily physical activity (PA), is likely to have greater individual variation than exercise-related activity thermogenesis and body size-dependent basal metabolic rate. Levine et al. (2) used inclinometers and triaxial accelerometers to reveal that obese participants were seated for 164 min/d more than and were upright for 152 min/d less than lean participants. Moreover, if the obese subjects had the same posture allocation as the lean subjects, they would have expended an additional 352 kcal/d. Therefore, NEAT has been highlighted recently for helping to prevent weight gain. However, there are currently few effective methods to objectively and noninvasively evaluate the type or quantity of low-intensity PA in free-living conditions.

Triaxial accelerometers that are small in size and minimally intrusive to normal subject movement can be useful

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[1] Nonstandard abbreviations: NEAT, non-exercise activity thermogenesis; EE, energy expenditure; PA, physical activity; IHC, indirect human calorimeter; mG, milligausse; $\dot{V}O_2$, oxygen uptake; $\dot{V}CO_2$, carbon dioxide production; SD, standard deviation; PAR, PA ratio; SEE, standard error of estimation.

devices for predicting PA EE (3). Previous studies demonstrated higher correlation coefficients between counts obtained with triaxial accelerometry and the EE measured by chamber in comparison with counts from uniaxial accelerometry (4–6). However, these previous studies researched moderate-intensity PA such as slow and brisk walking and jogging, not low-intensity lifestyle activities. Moreover, Bassett et al. (7) found that uniaxial waist-mounted accelerometers overestimated the EE of walking and underestimated the EE of all other activities. Thus, we hypothesized that methods for estimating EE would be improved by the development of equations for each daily lifestyle PA.

To accurately predict EE using equations for each activity, it is necessary to classify each daily lifestyle PA using triaxial accelerometry. There are currently no published data concerning the identification of body posture in free-living conditions using triaxial accelerometry, especially light-to-moderate intensity PA with upper body movement such as sweeping, mopping, and window washing, which is a relatively high-energy cost during daily living (4,7). However, a previous study that evaluated standing balance using a triaxial accelerometer found that the accelerometer measurements, especially horizontal acceleration, were able to distinguish between the different test conditions and simultaneous force platform measurements (8). Concomitantly, it is speculated that household activities with upper body movement (e.g., cleaning and sweeping) may have larger horizontal acceleration than sitting and standing. We hypothesized that low-intensity PA in free-living conditions can be identified by using horizontal acceleration obtained from triaxial accelerometry.

Thus, the purpose of the present study was to develop regression-based equations that estimate EE from total acceleration, which was based on the defined thresholds of accelerations that can be used to delineate low-to-moderate intensity PA. Furthermore, we compared the ability to identify the type and quantity of the low-intensity PA and predicted EE using either triaxial acceleration or only vertical acceleration from a triaxial accelerometer.

## Research Methods and Procedures

### *Subjects*

Twenty-one Japanese adults (8 men and 13 women) living in the Tokyo metropolitan area were recruited for the study (Table 1). All subjects were adults (≥20 years) and were without any chronic diseases that could affect EE or daily PA. All subjects received a verbal and written description of the study and gave their informed consent to participate before testing. The study protocol was approved by the Ethical Committee of the National Institute of Health and Nutrition.

**Table 1.** Subject characteristics

| | **Men** ($n$ = 8) | **Women** ($n$ = 13) |
|---|---|---|
| Age (yrs) | 33 ± 15 | 31 ± 10 |
| Standing height (cm) | 171.2 ± 4.7 | 161.0 ± 5.3 |
| Body weight (kg) | 65.3 ± 4.1 | 55.8 ± 9.8 |
| BMI (kg/m$^2$) | 22.3 ± 2.0 | 21.5 ± 3.5 |
| Fat (%) | 13.2 ± 3.7 | 23.3 ± 8.4 |
| Fat-free mass (kg) | 52.0 ± 5.8 | 32.6 ± 5.4 |

### *Anthropometry*

Body weight was measured on a digital balance to the nearest 0.1 kg, and height was measured on a stadiometer to the nearest 0.1 cm. BMI was calculated as the body weight in kilograms divided by the height in meters squared. Body composition was evaluated by the skinfold method at two skinfolds (triceps and subscapular) to the nearest 0.1 mm. The measurements were repeated until the difference between the two readings reached within 1 mm, and the mean value was used. Body density was assessed using the equations for Japanese (9), and the percentage of body fat was estimated using the equation of Brozek et al. (10). Body fat mass and the fat-free mass were calculated from body weight and percent of body fat.

### *Study Protocol*

Subjects were fitted at the left hip with a triaxial accelerometer (AC-301, 51 × 77 × 15 mm, 87 grams; or AC-210, 48 × 67 × 16 mm, 57 grams; GMS, Tokyo, Japan) while also in the indirect human calorimeter (IHC) for 22.5 hours (from 6 PM to 4:30 PM the next day). The triaxial accelerometer obtained three-dimensional accelerations every 40 ms with a sensitivity of 2 milligausse (mG) and a band-pass filter of 0.3 to 100 Hz. The acceleration count was calculated as the average of the absolute values for acceleration in each direction for a given interval (1 minute). The subjects ate breakfast, lunch, and dinner at 8:15 AM, 12:30 PM, and 6:30 PM, respectively. They went to bed at 11 PM and were gently awakened at 7 AM. They were permitted to go to the toilet and were asked to return to bed immediately. The schedule included 8 sessions of standardized activities: 2 × 30 minutes sessions each of walking on a treadmill (95 m/min in the morning and 71 m/min in the afternoon), sitting, standing, and housework representative of typical activities in free-living conditions. Subjects were permitted to spend time freely in a sitting or standing position as long as posture was maintained and to rest periodically during the housework period. During the remaining time periods, subjects were only permitted to do light activities such as reading, writing, viewing television, dressing, and undressing. They were asked to refrain from sleeping and planned strenuous exercise except during the walking periods. Meals were given three times a day to provide the predicted basal metabolic rate (11) multiplied by the estimated PA level (1.5).

### *IHC*

An open-circuit IHC was used to evaluate the EE of the four standardized activities totaling 4 hours, the sleeping time for 8 hours, and the residual time for 10.5 hours. Details of IHC have been reported previously (12,13). Briefly, the respiratory chamber was an air-tight room (20,000 liters), equipped with a bed, desk, chair, television with video deck, compact disc player, telephone, toilet, sink, and treadmill. The temperature and relative humidity in the room were controlled at 25 °C and 55%, respectively. The $O_2$ and $CO_2$ concentrations of the air supply and exhaust were measured by mass spectrometry. For each experiment, the gas analyzer (ARCO-1000A-CH; Arco System, Inc., Kashiwa, Japan) was initially calibrated using a certified gas mixture and atmospheric air. The flow rate exhausted from the chamber was measured by pneumotachograph (FLB1; Arco System, Inc.). The flow meter was calibrated before each measurement, and the flow rate was maintained at ~60 L/min. Oxygen uptake ($V\text{O}_2$) and carbon dioxide production ($V\text{CO}_2$) were determined by the flow rate of exhaust from the chamber and the concentrations of the inlet and outlet air of the chamber, respectively (12). Values of $V\text{O}_2$ and $V\text{CO}_2$ were expressed under the conditions of standard temperature and pressure and under dry conditions. EE was estimated from $V\text{O}_2$ and $V\text{CO}_2$ using Weir's equation (14). The accuracy and precision of our IHC for measuring EE as determined by the alcohol combustion test was 99.8 ± 0.5% [mean ± standard deviation (SD)] in 6 hours and 99.4 ± 3.1% in 30 minutes. Sleeping metabolic rate was defined as the average EE over 8 hours of sleep. The PA ratio (PAR) was calculated as the EE during sitting, standing, housework, or walking periods divided by the sleeping metabolic rate.

### *Identification of the Types for PA*

Minute-to-minute anterior-posterior (x-axis), mediolateral (y-axis), vertical (z-axis), and total (synthesized triaxes) accelerations were obtained from a triaxial accelerometer during four standardized periods (sitting, standing, housework, and walking on a treadmill, 2 × 30 minutes each activity). Twenty-eight of the 30 minutes of each structured period, which excluded the first and last minute of each session, were used for the analysis (i.e., 28 data points × two replicate sessions × 21 subjects = 1176 data points for four types of activity). One of the acceleration data for walking on a treadmill at 71 m/min was excluded for the analysis because the subject walked at a different speed. In addition, because the hip-fitted triaxial accelerometer could shift horizontally while the subject was in the IHC, anterior-posterior (x-axis) and mediolateral (y-axis) were synthesized as horizontal acceleration for the analysis. Optimal thresholds for classifying total acceleration and the ratio of vertical to horizontal acceleration into sitting, standing, housework, and walking were determined by receiver operating characteristic analysis, which is the standard approach to evaluate the sensitivity and specificity of test results. We adopted the acceleration for the highest product of sensitivity and specificity as optimal thresholds for each binary classification. Furthermore, the threshold of each activity was defined using only vertical acceleration.

### *Prediction and Validation of EE*

The total accelerations from the different periods and the data's relationship to PAR obtained from the IHC allowed for the development of EE equations for four types of activity (sitting, standing, housework, and walking). The averaged value of minute-to-minute total acceleration for each activity was used for the analysis (i.e., one data point × 21 subjects = 21 data points for four types of activity), which corresponded to the 30-minute averaged PAR data obtained by IHC. The validation of the EE equations was tested on the residual time (10.5 hours). Initially, the minute-to-minute total acceleration for the residual time was classified into four types of activity using thresholds we developed. Subsequently, the PAR for each minute was predicted using a selected equation among four types of regression-based equations and/or constant value. The estimated EE for 1 minute was calculated as follows: the predicted PAR × the measured sleeping metabolic rate, which is a highly stable value in IHC. The estimated EE per 1 minute for the residual time (i.e., 630 minutes = 10.5 hours) was totaled. We investigated the validity of the equations by comparing the EE measured by IHC with the EE estimated using the developed equations. Similarly, in cases that only utilized vertical acceleration, the development and validation of equations were conducted.

### *Supplementary Experiment*

To supplement the data of housework and walking, additional protocols that tested these activities were conducted using the same triaxial accelerometer and a portable gas analyzer (Metamax3B; CORTEX, Leipzig, Germany). Japanese adults (5 men and 7 women) 21 to 38 years old were recruited for the study. The measurement time was 4 minutes for housework (pull up weeds and sweep up) and 5 minutes for walking (walk in place and walk slowly). The relationship between the acceleration data (mG) from the different periods and PAR was tested.

### *Statistics*

Statistical analyses were performed using SPSS for Windows (version 10.0; SPSS, Inc., Chicago, IL). All results are

**Table 2.** Minute-to-minute acceleration data for each activity

| Activity | Acceleration (mG) Total | Horizontal | Vertical | Vertical/ Horizontal |
|---|---|---|---|---|
| Sit | 6.1 ± 8.5 | 3.5 ± 6.7 | 0.7 ± 2.3 | 0.05 ± 0.17 |
| Stand | 19.0 ± 20.8 | 13.0 ± 16.2 | 4.4 ± 7.3 | 0.18 ± 0.21 |
| Housework | 52.8 ± 31.6 | 37.5 ± 23.6 | 18.7 ± 14.0 | 0.44 ± 0.22 |
| Walk | 436.3 ± 107.7 | 261.2 ± 62.7 | 281.1 ± 87.3 | 1.08 ± 0.27 |

mG, milligausse.

presented as the mean ± SD. The relationship between two variables was evaluated by Pearson's and Spearman's correlation. The percentage difference was calculated as follows: [(predicted value − measured value)/measured value] × 100. Agreement of EE between the predicted and measured values was further examined by plotting the difference in predicted values against the mean with limits of agreement (mean difference ± 2 SD of the differences, which gives an indication of the precision of the method), as suggested by Bland and Altman (15). Differences were regarded as significant when the probabilities were <0.05.

## Results

The physical characteristics of the subjects are shown in Table 1. In general, the mean values were comparable with those obtained in the National Nutrition Survey, although a slightly larger variation was observed for body weight among women. Means and SD of total, horizontal, and vertical acceleration and the ratio of vertical-to-horizontal acceleration for structured activities are listed in Table 2. Only the vertical-to-horizontal acceleration ratio for walking exceeded 1.00. The resulting receiver operating characteristic curve characterized the performance of a binary classification by describing the trade-off between sensitivity and specificity over an entire range of possible thresholds (Table 3). The thresholds for sitting vs. standing and standing vs. housework were classified by total acceleration. Because it is possible to combine the total acceleration between housework and walking activities, the threshold for housework vs. walking was determined by the vertical-to-horizontal acceleration ratio and 30 mG or more of total acceleration. Sensitivities and specificities were >75% for each combination of two activities, except for specificity of sitting vs. standing. Moreover, when classifying PA by the

**Table 3.** Threshold, sensitivity, and specificity (%) for each activity

| Activity | Acceleration (mG) Total | Vertical/ horizontal | Sensitivity (%) | Specificity (%) | |
|---|---|---|---|---|---|
| When using tri-axes acceleration: | | | | | |
| Sit | <7 | <0.750 | 75.3 | 64.6 | Sit vs. stand |
| Stand | 8 to 29 | <0.750 | 78.9 | 76.3 | Stand vs. housework |
| Housework | >30 | <0.750 | 95.9 | 94.5 | Housework vs. walk |
| Walk | >30 | >0.751 | | | |
| When using vertical acceleration: | | | | | |
| Sit | <7 | | | | Sit vs. stand |
| Stand | <7 | | 82.4 | 73.5 | Stand vs. housework |
| Housework | 8 to 99 | | 99.8 | 99.5 | Housework vs. walk |
| Walk | >100 | | | | |

mG, milligausse.

**Table 4.** Prediction equation for each activity

| Activity | PAR | | |
|---|---|---|---|
| | Model | $R^2$ | SEE |
| When using tri-axes acceleration: | | | |
| Sit | 1.3786 | | |
| Stand | 0.0093AC (mG) + 1.3566 | 0.66 | 0.05 |
| Housework | 0.0123AC (mG) + 1.7208 | 0.45 | 0.18 |
| Walk | 0.0081AC (mG) + 0.9234 | 0.72 | 0.32 |
| When using vertical acceleration | | | |
| Sit<br>Stand | 0.0329AC (mG) + 1.3846 | 0.51 | 0.02 |
| Housework | 0.0333AC (mG) + 1.7316 | 0.60 | 0.13 |
| Walk | 0.0092AC (mG) + 1.8443 | 0.64 | 0.29 |

PAR, physical activity ratio; SEE, standard error of the estimate; AC, acceleration count; mG, milligausse.

threshold in the present study, the percentage of each classified PA was calculated during standardized periods of sitting (sitting, 75.3%; standing, 22.2%; housework, 2.5%; and walking, 0%), standing (sitting, 35.4%; standing, 43.5%; housework, 20.6%; and walking, 0.5%), housework (sitting, 8.2%; standing, 15.5%; housework, 72.4%; and walking, 3.8%), and walking (sitting, 0%; standing, 0.4%; housework, 5.1%; and walking, 94.4%). The same thresholds were also obtained by discriminant analysis. In contrast, when using vertical acceleration only, standing, housework, and walking activities were identified as accurately as total acceleration (sensitivity and specificity: standing vs. housework, 82% and 74%; housework vs. walking, 99% and 99%); however, it was not possible to distinguish between sitting and standing positions.

The averaged values of PAR were 1.38 ± 0.07 for sitting, 1.54 ± 0.18 for standing, 2.39 ± 0.27 for housework, and 4.34 ± 0.84 for walking, which corresponded to total acceleration values of 7.0 ± 2.9, 19.5 ± 14.7, 54.2 ± 14.6, and 426.0 ± 95.3 mG, respectively. Significant simple correlations were observed between PAR obtained by IHC and total acceleration obtained by triaxial accelerometry for standing, housework, and walking [$R^2$ = 0.45 to 0.72, $p < 0.01$, standard error of estimation (SEE) = 0.05 to 0.32] (Table 4, Figure 1A). Because PAR for sitting was not associated with total acceleration, the averaged value of PAR (i.e., 1.3786) was used for predicting EE. Thresholds between the activities and three equations, or a constant value, for each kind of activity to predict EE were applied to the residual time for validation. There was a strong correlation between the measured and predicted EE ($r$ = 0.94, $p < 0.01$) (Figure 2), although the predicted EE (882 ± 150 kcal/10.5 hours) was slightly higher than the EE measured by IHC (846 ± 146 kcal/10.5 hours; 4.4 ± 6.2% difference) (Figure 3). The same analyses were also performed using only vertical acceleration. Three EE equations (1, sitting and standing; 2, housework; 3, walking) were developed using only vertical acceleration ($R^2$ = 0.51 to 0.64, $p < 0.01$, SEE = 0.02 to 0.29) (Table 4) but overestimated EE ($p < 0.01$) (981 ± 181 kcal/10.5 hours, 16.0 ± 10.0% difference).

In the supplemental experiment, the average values of PAR and total acceleration were, respectively, 3.22 and 91.8 mG in men ($n$ = 5), and 3.12 and 85.3 mG in women ($n$ = 7) for pulling up weeds and 3.12 and 106.4 mG in men and 3.16 and 117.6 mG in women for sweeping up, which were categorized as housework in our study (Figure 1B, open triangle). Similarly, the PAR and total acceleration were, respectively, 2.90 and 170.2 mG in men, and 2.84 and 188.2 mG in women for walking in place and 3.21 and 202.1 mG in men and 2.84 and 218.1 mG in women for walking slowly, which were categorized as walking (Figure 1B, closed rhombus).

## Discussion

The major finding of this study is that we can accurately identify four different periods of activity (i.e., sitting, standing, housework, and walking) using total acceleration and the vertical-to-horizontal acceleration ratio obtained from a triaxial accelerometer under close-to-normal living conditions. When we used vertical accelerations only, it was not possible to distinguish between sitting and standing positions. In addition, the sensitivity and specificity between housework and walking using the vertical-to-horizontal acceleration ratio, which was our original method, was over 90%. A recent study found that the time allocated to sitting and standing was closely related to weight gain (2). Moreover, PA with upper body movement such as housework has a relatively high energy cost during daily living (4,7).

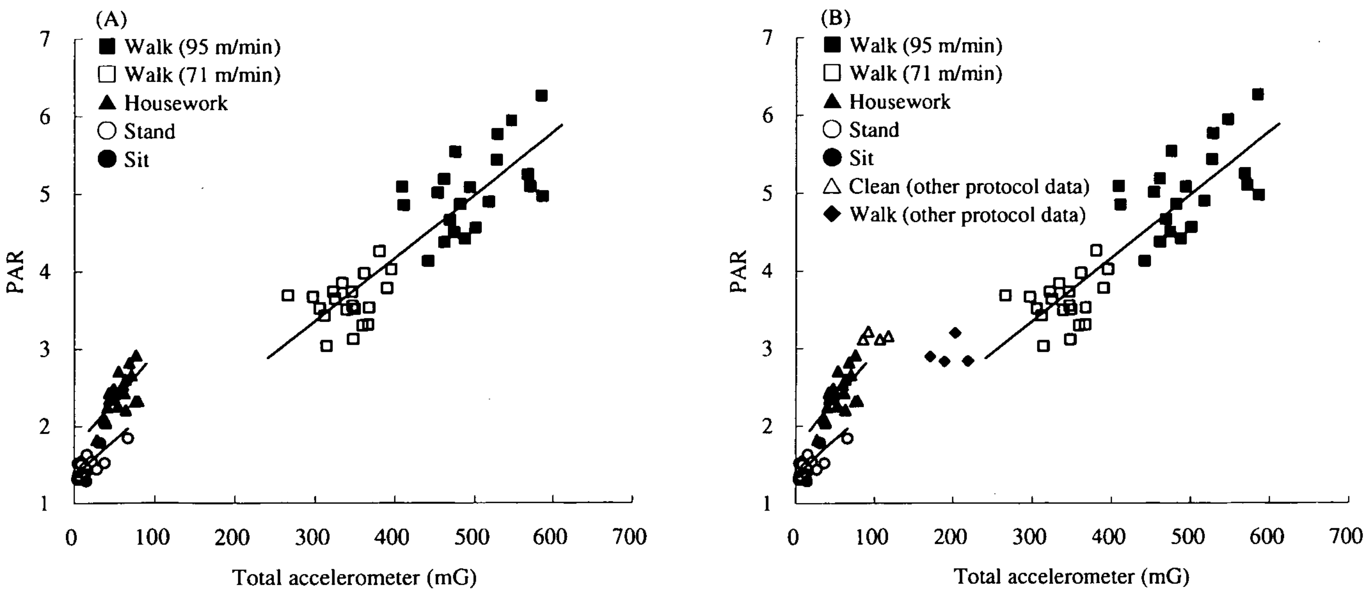


*Figure 1:* Relationship between total acceleration and PAR. Original data (A) with additional protocol data (B).

Therefore, the classification of daily lifestyle PA in our study could be a significant contribution to weight management, especially in the area of clinical practice.

Additionally, we found a high validation of predicting EE in low-intensity PA. Our results indicate that EE measured by chamber was closely correlated with EE estimated using the three equations and one constant value (percentage difference, 4.4%; correlation coefficient, 0.94; SEE, 61 kcal/10.5 hours). Although a previous study that estimated daily EE using triaxial accelerometry was limited, the percentage difference between EE measured by chamber and EE estimated by the developed non-linear model using Tritrac (triaxial accelerometer) was small (16). Moreover, Plasqui et al. (17) observed the relationship between total EE measured by the doubly labeled water technique for 15

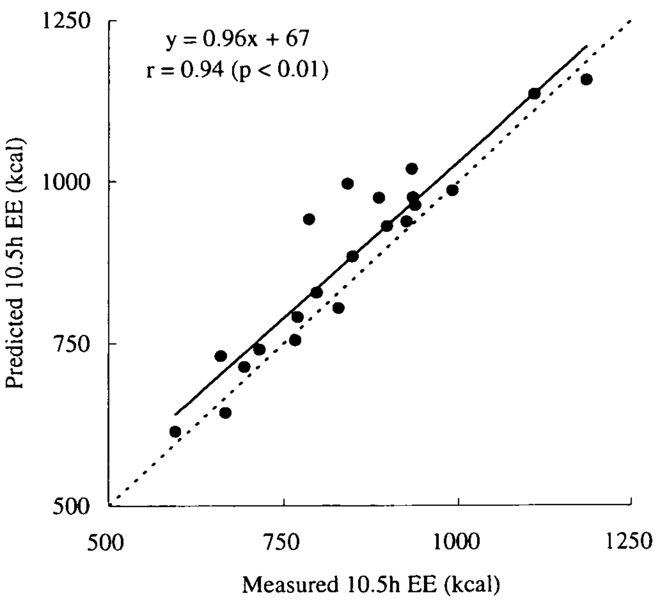


*Figure 2:* Relationship between measured and predicted 10.5-hour EE.

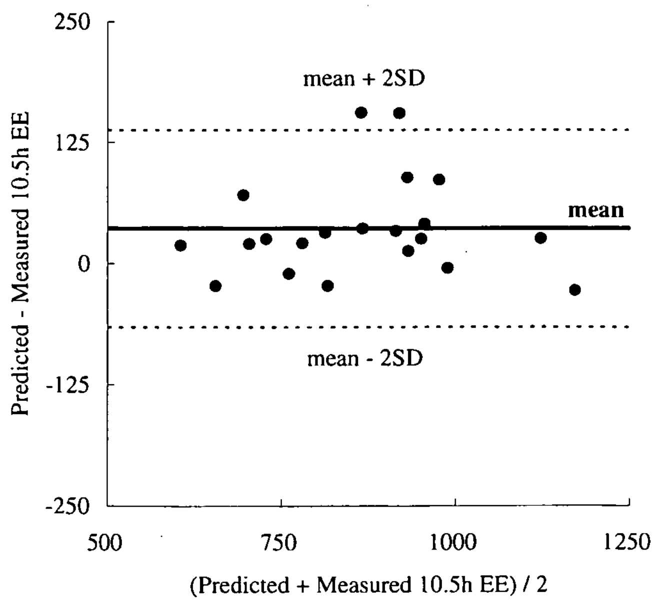


*Figure 3:* Bland and Altman analysis. The differences between measured and predicted 10.5-hour EE are plotted against the measured and predicted mean 10.5-hour EE.

consecutive days and the predicted EE using the equation of counts for Tracmor (triaxial accelerometer), age, weight, and height as parameters. These authors indicated that the correlation coefficient was 0.90, and SEE was 167 kcal/d between measured and predicted EE. Our study presents a novel method to objectively evaluate EE of low-intensity PA under close-to-normal living conditions using triaxial accelerometry that compares favorably with the previous study.

We believe that our highly accurate prediction of EE for low-intensity PA is due to the method used to develop each equation for standing, housework, and walking. A previous study reported that an equation based on the acceleration of walking underestimated EE of moderate-intensity lifestyle activities (7). Recently, Crouter et al. (18) found that the estimation of EE both in walking and lifestyle activity could be improved by the two regression lines. In the present study, if only one equation was developed from the relationship between total acceleration and PAR of all plots, including sitting, standing, housework, and walking [EE kcal = 0.0068 × acceleration count (mG) + 1.5509], the predicted EE of residual time (10.5 hours) would be overestimated (931 ± 155 kcal/10.5 hours, $p < 0.01$, 10.3 ± 5.2% difference). One possible explanation for this overestimation is that EE of static body posture such as sitting and standing may be overestimated by all plots included in the equation. Thus, the developed equations for each daily lifestyle PA are a novel method for predicting EE.

A previous study compared the ability to predict EE using uniaxial and triaxial accelerometry (7,19). The results indicated that triaxial accelerometry had higher accuracy of estimating EE than uniaxial accelerometry. However, as Plasqui et al. (17) pointed out, because two devices from different manufacturers were used, no conclusions can be drawn regarding the possible benefits of triaxial vs. uniaxial accelerometry. When Plasqui et al. (17) initially observed the contributions of vertical and horizontal acceleration to total EE per day adjusted for weight, height, and age, vertical acceleration explained an additional 16% of the variation in total EE. Furthermore, because horizontal acceleration contributed another 5%, it was concluded that triaxial accelerometers are more suitable than uniaxial accelerometers for estimating daily life activities. Similarly, the present study also compared the ability to quantitate low-intensity PA using either triaxial acceleration or only vertical acceleration from a triaxial accelerometer. Our results demonstrate that EE equations developed using only vertical acceleration overestimated EE by 135 kcal/10.5 hours. Further analysis of our data shows that there is no difference in EE for sitting and standing between equations using triaxial acceleration and only vertical acceleration (triaxial, 681 kcal/10.5 hours vs. uniaxial, 672 kcal/10.5 hours, $p = 0.06$), whereas the equation using only vertical acceleration overestimated the EE of housework periods by 109 kcal/10.5 hours (triaxial, 195 kcal/10.5 hours vs. uniaxial, 304 kcal/10.5 hours, $p < 0.01$). Therefore, we conclude that a triaxial accelerometer has a higher ability to predict EE of low-intensity PA, especially when the activity includes a large variation in horizontal acceleration, such as housework. Additionally, the technique of using not only total acceleration but also the vertical-to-horizontal acceleration ratio can be emphasized as a merit of the three-dimensional accelerometer.

There are some limitations of this study. The first limitation concerns the validity of the equations developed by comparing the EE measured by IHC with the EE estimated using developed equations for the residual time (i.e., 630 minutes = 10.5 hours). It is noted that this approach tends to overestimate the validity of the methods developed. We need to test the prediction equations of the present study in free-living conditions using the doubly labeled water method. The second limitation was that total acceleration data from 100 to 250 mG were blank during the chamber stay, although the relationship between PAR and total acceleration allowed for the development of EE equations for each activity. However, the plots describing the relationship between PAR and total acceleration for housework and walking in the supplemental experiment were likely to be an extension of the regression line, explaining this relationship in both activities in the present study. The results indicate that either of the equations for housework and walking can be applied to the range of 100 to 250 mG for total acceleration. Another limitation is that we did not develop an equation for cycling, which is a very popular lifestyle PA. Future studies should apply to all types of lifestyle activities. Lastly, the reason for the slight overestimation of the EE/10.5 hours in the present study should be clarified.

In conclusion, we identified low-intensity PA with high accuracy using total acceleration and the vertical-to-horizontal acceleration ratio obtained from a triaxial accelerometer. Notably, the use of the vertical-to-horizontal acceleration ratio is a novel method. Due to the classification of low-intensity PA, it is possible to accurately predict EE using equations for each activity. We demonstrated that triaxial accelerometry, when the total, vertical, and horizontal accelerations are utilized, can effectively evaluate different types of activities and estimate EE for low-intensity physical activities associated with modern lifestyles. In combination with measured or a highly accurately predicted sleeping metabolic rate (20), EE in sedentary lifestyle can be obtained.

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*Original Article*

# Accuracy of Predictive Equations for Basal Metabolic Rate and Contribution of Abdominal Fat Distribution to Basal Metabolic Rate in Obese Japanese People

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## *Abstract*

**BACKGROUND:** Large errors may occur when predicting basal metabolic rate (BMR) based on physical characteristics in obese people. In addition, the contribution of abdominal visceral fat to BMR remains controversial. This study examined the accuracy of several predictive equations for BMR and the contribution of abdominal fat distribution to BMR in obese Japanese participants in the Saku Control Obesity Program (SCOP).
**METHODS:** BMR was determined using a mask and Douglas bag in adult males (n = 12) and females (n = 11). We measured abdominal subcutaneous and visceral fat areas using computerized tomography.
**RESULTS:** All the equations, with the exception of Bernstein's, overestimated BMR in obese males. Some equations, including the Japan-Dietary Reference Intakes and the Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University (FAO/WHO/UNU) equations, overestimated BMR in obese females, while the Harris-Benedict and Henry equations provided relatively accurate predictions of BMR in obese females. We found no correlation between abdominal visceral fat area and BMR when adjusted for sex, fat-free mass, and abdominal subcutaneous fat area (partial r =−0.022). Abdominal subcutaneous fat area correlated significantly with BMR when adjusted for sex, fat-free mass, and abdominal visceral fat area (partial r = 0.732), although this correlation was no longer significant after adjustment for total fat mass (partial r = 0.266).
**CONCLUSIONS:** In obese Japanese subjects, most the predictive equations overestimated BMR in males, whereas some equations were relatively accurate for females. Our findings indicate abdominal fat distribution may not be independently related with BMR.

***KEY WORDS:*** Basal metabolic rate, obese, predictive equation, abdominal visceral fat

## *Introduction*

Basal metabolic rate (BMR) constitutes the largest component of total energy expenditure in the majority of people. Because BMR can be predicted from simple anthropometric measurements, it is often used to estimate total energy expenditure.

Many equations have been developed for estimating basal or sleeping metabolic rates based on anthropometric measurements, age, and sex.[1,2)] These equations can be helpful when actual metabolic measurements are not available. It has been shown in Caucasians, however, that BMR is considerably more difficult to predict in obese than in normal-weight subjects.[2-5)] Studies have found that predictive equations overestimate BMR and/or that large prediction errors may occur in obese subjects.[2-5)] In addition, most of the equations currently available apply only to Caucasians. The validity of the predictive equations has not been examined in obese Japanese subjects, despite several studies showing that some of the predictive equations are not applicable to nonwhite populations.[6-9)]

In addition, the contribution of abdominal fat distribution to BMR remains controversial. Some studies have shown a relationship between abdominal visceral fat (AVF) area and BMR or resting metabolic rate,[10-14)] whereas others have not.[15-17)] To our knowledge, no study has examined these relationships in Japanese subjects using computerized tomography (CT), with the exception of Okura et al, who investigated the relationship in healthy elderly subjects.[14)] They reported that adjusted resting energy expenditure correlated inversely with AVF but not with abdominal subcutaneous fat (ASF). While significant, this relationship with AVF was relatively weak (r = −0.131).

In the present study, we examined the validity of predictive equations for BMR in obese Japanese men and women. The contribution of abdominal fat distribution, as measured by CT, to BMR was also examined.


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## Methods

### Subjects

The subjects in the study were 50- to 54-year-old obese subjects (12 males and 12 females) residing in Saku city. They were randomly selected from among the participants in the Saku Control Obesity Program (SCOP), the details of which are described elsewhere in this supplement.[18,19] The measurements of BMR for one of the female subjects failed; therefore, data for 12 males and 11 females were used in the present study.

The study protocol was approved by the Ethics Committees of the National Institute of Health and Nutrition and Saku Central Hospital. The study protocol was explained to the subjects prior to enrollment, and all subjects provided their informed consent.

### Basal Metabolic Rate

The subjects reported to the hospital for the series of measurements at approximately 8 am on the study day. BMR was measured in the supine position and in the post-absorptive state (12 hours or longer after the last meal). The temperature in the room was controlled at 24–26°C. The measurement was performed using a mask and Douglas bag for 20 minutes with 1 minute of intermission. The volume of expired air was measured with a certified dry gas meter (Shinagawa DC-5, Tokyo, Japan). The expired air was sampled and the $O_2$ and $CO_2$ concentrations were measured using a gas analyzer (Arco System, AR-1, Kashiwa, Japan) with a galvanic $O_2$ sensor and an infrared $CO_2$ sensor. For each of the consecutive measurements, the gas analyzer was calibrated initially using atmospheric air. The values of $O_2$ consumption and $CO_2$ production were expressed under standard temperature, pressure, and dry air conditions. BMR was estimated from $O_2$ consumption and $CO_2$ production using Weir's equation.[20]

### Anthropometric Measurements

Body weight was measured to the nearest 0.1 kg and height to the nearest 0.1 cm using a stadiometer. The measurements were performed in light clothing and underwear. Body mass index (BMI) was calculated as weight (kg) divided by square of height ($m^2$). Percentage body fat was evaluated by the bioelectric impedance method (Tanita, BF-220, Tokyo, Japan).

To assess ASF and AVF levels, a CT scan was performed at the level of the umbilicus, with the subject in the supine position. ASF and AVF areas were determined using commercially available software (Fat Scan; N2 System Corp., Osaka, Japan).[21] The attenuation range of CT numbers for ASF was set as the mean ± 3 standard deviation (SD).

### Predictive Equations of Basal Metabolic Rate

The predictive equations of Japan-Dietary Reference Intakes (DRI),[22] Harris and Benedict,[23] the Food and Agriculture Organization of the United Nations/World Health Organization /United Nations University (FAO/WHO/UNU),[24] Henry,[25] Owen,[26,27] Mifflin,[28] and Bernstein[29] were evaluated (***Table 1***). For the Japan-DRI equations, the Ministry of Health and Welfare proposed adjusting for body weight.[30] Therefore, the equations including this adjustment were also examined. For the FAO/WHO/UNU equations, those using body weight only are often used. However, in the present study, equations using body weight and height were also examined.

### Statistical Analyses

The results are presented as the mean ± SD. The % difference of the prediction error was calculated as the residual divided by the measured value for each subject. The relationship between measured and predicted values of BMR and anthropometric measurements was examined using Pearson's correlation. Sex was treated as a binomial variable (0 for males, 1 for females) and was adjusted for in the partial correlation analysis. Adjustment for age was not performed because the range was small (50–54 years). Statistical significance was set at $p < 0.05$ for all predictors. The statistical analyses were performed using SPSS® for Windows (version 14.0; SPSS Inc., Chicago, IL, USA).

***Table 1 Predictive equations for basal metabolic rate used in the present study***

| Predictive equations (kcal/day) | Males | Females |
|---|---|---|
| Japan-DRI [22] | weight × 21.5 | weight × 20.7 |
| Japan-DRI with adjustment for body weight [22,30] | [21.5 + (10.8 - 0.173 × weight)] × weight | [20.7 + (8.9 - 0.172 × weight)] × weight |
| Harris and Benedict [23] | 66 + (13.7 × weight) + (5.0 × height) – (6.8 × age) | 665 + (9.6 × weight) + (1.8 × height) – (4.7 × age)] |
| FAO/WHO/UNU (body weight) [24] | 879 + (11.6 × weight) | 829 + (8.7 × weight) |
| FAO/WHO/UNU (body weight and height) [24] | 901 + (11.3 × weight) + (16.0 × height/100) | 865 + (8.7 × weight) – (25.0 × height/100) |
| Henry [25] | [(59.2 × weight + 2480)]/4.184 | [(40.7 × weight + 2900)]/4.184 |
| Owen [26,27] | 879 + (10.20 × weight) | 795 + (7.18 × weight) |
| Mifflin [28] | 5 + (9.99 × weight) + (6.25 × height) – (4.92 × age) | –161 + (9.99 × weight) + (6.25 × height) – (4.92 × age) |
| Bernstein [29] | –1032 + (11.0 × weight) + (10.2 × height) – (5.8 × age) | 844 + (7.48 × weight) – (0.42 × height) – (3.0 × age) |

weight: kg, height: cm, age: year.
Predictive equations for 50 to 54-yr-old obese subjects were used.

## *Results*

The physical characteristics of the subjects are summarized in ***Table 2***. There was a similar degree of correlation between the measured and predicted values of BMR for the various predictive equations (r = 0.839–0.859). The relationships between measured and predicted BMR based on the Japan-DRI, DRI-adjusted, Harris-Benedict, and Bernstein equations are shown in ***Figures 1 and 2***. In obese males, the majority of equations overestimated BMR, particularly for those with lower BMR (***Figure 1***), whereas Bernstein's equation significantly underestimated BMR (***Table 3***). In particular, the Japan-DRI and FAO/WHO/UNU equations overestimated BMR to the greatest extent. The Mifflin equation provided a better prediction of BMR, while the equation overestimated BMR. In obese females, the Japan-DRI and FAO/WHO/UNU equations overestimated BMR, whereas the Harris-Benedict and Henry equations provided a relatively accurate prediction of BMR (***Figure 2***). In both sexes, adjustment for body weight in the Japan-DRI equations attenuated the overestimation of BMR, although the value still remained too high. In addition, the FAO/WHO/UNU equations with or without body height provided almost identical values. The SD of the % difference of the predicted BMR was comparable between the various equations.

Following adjustment for sex and fat-free mass, BMR correlated significantly with ASF (r = 0.806, $p < 0.001$) and AVF (r = 0.493, $p < 0.05$). When sex, fat-free mass, and ASF were adjusted for, BMR was not correlated with AVF (r = −0.022, n.s.). The relationships between AVF and residual of BMR adjusted for sex, fat-free mass, and ASF is shown in ***Figure 3***. On the other hand, BMR correlated significantly with ASF when adjusted for sex, fat-free mass, and AVF (r = 0.732, $p < 0.001$); however, this correlation was no longer significant after additional adjustment for total fat mass (r = 0.266, n.s.).

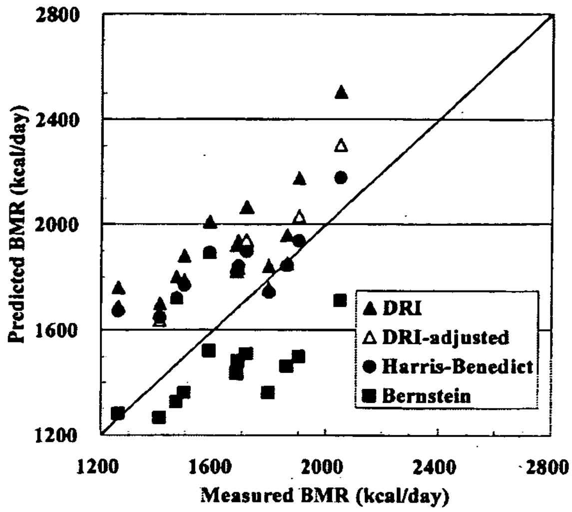


*Fig. 1.* Relationships between measured and predicted basal metabolic rate (BMR) in obese males. DRI: Japan-Dietary Reference Intakes.

***Table 2 Physical characteristics of subjects***

| | Mean± SD | Range |
|---|---|---|
| **Males** | | |
| Age (year) | 52 ± 1 | 50.0 - 54.0 |
| Body height (cm) | 172.8 ± 3.9 | 168.8 - 179.2 |
| Body weight (kg) | 91.3 ± 10.0 | 79.1 - 116.5 |
| Body mass index (kg/m$^2$) | 30.6 ± 3.3 | 27.7 - 39.2 |
| Percentage of body fat (%) | 28.3 ± 4.9 | 23.4 - 39.2 |
| Abdominal subcutaneous fat area (cm$^2$) | 272 ± 80 | 163 - 436 |
| Abdominal visceral fat area (cm$^2$) | 165 ± 51 | 98 - 289 |
| **Females** | | |
| Age (year) | 53 ± 2 | 50.0 - 54.0 |
| Body height (cm) | 158.6 ± 5.8 | 152.0 - 169.3 |
| Body weight (kg) | 82.5 ± 12.2 | 69.3 - 109.7 |
| Body mass index (kg/m$^2$) | 32.7 ± 3.8 | 28.4 - 40.0 |
| Percentage of body fat (%) | 44.3 ± 7.0 | 34.7 - 62.5 |
| Abdominal subcutaneous fat area (cm$^2$) | 383 ± 96 | 250 - 619 |
| Abdominal visceral fat area (cm$^2$) | 140 ± 57 | 84 - 266 |

SD: standard deviation

***Table 3 Measured and predicted basal metabolic rate in obese people***

| | Values(kcal/day) | | %difference(%) | |
|---|---|---|---|---|
| | Mean± SD | Range | Mean± SD | Range |
| **Males** | | | | |
| **Measured** | 1659 ± 226 | 1262 - 2051 | | |
| **Predicted** | | | | |
| Japan-DRI [22] | 1963 ± 216 | 1701 - 2505 | 19.2 ± 9.8 | 2.7 - 39.6 |
| Japan-DRI with adjustment for body weight [22,30] | 1856 ± 178 | 1639 - 2304 | 12.8 ± 9.7 | -2.1 - 33.8 |
| Harris and Benedict [23] | 1831 ± 142 | 1648 - 2178 | 11.4 ± 10.0 | -2.9 - 32.5 |
| FAO/WHO/UNU (body weight) [24] | 1938 ± 116 | 1797 - 2230 | 18.2 ± 12.0 | 4.2 - 45.0 |
| FAO/WHO/UNU (body weight and height) [24] | 1961 ± 113 | 1822 - 2245 | 19.6 ± 12.3 | 5.4 - 46.9 |
| Henry [25] | 1885 ± 142 | 1712 - 2241 | 14.8 ± 10.7 | 0.7 - 38.8 |
| Owen [26,27] | 1811 ± 102 | 1686 - 2067 | 10.5 ± 11.4 | -2.7 - 35.9 |
| Mifflin [28] | 1744 ± 108 | 1601 - 1996 | 6.3 ± 10.3 | -6.4 - 28.2 |
| Bernstein [29] | 1436 ± 125 | 1267 - 1713 | -12.7 ± 7.4 | -24.0 - 1.7 |
| **Females** | | | | |
| **Measured** | 1477 ± 210 | 1192 - 1895 | | |
| **Predicted** | | | | |
| Japan-DRI [22] | 1709 ± 253 | 1435 - 2271 | 15.8 ± 7.2 | -1.8 - 24.5 |
| Japan-DRI with adjustment for body weight [22,30] | 1599 ± 210 | 1372 - 2064 | 8.6 ± 6.6 | -6.2 - 18.5 |
| Harris and Benedict [23] | 1496 ± 126 | 1367 - 1777 | 2.1 ± 8.0 | -7.5 - 15.7 |
| FAO/WHO/UNU (body weight) [24] | 1547 ± 106 | 1432 - 1783 | 5.8 ± 9.2 | -5.9 - 21.9 |
| FAO/WHO/UNU (body weight and height) [24] | 1543 ± 106 | 1430 - 1778 | 5.6 ± 9.2 | -6.2 - 21.6 |
| Henry [25] | 1496 ± 119 | 1367 - 1760 | 2.2 ± 8.2 | -7.1 - 16.7 |
| Owen [26,27] | 1388 ± 88 | 1293 - 1583 | -5.0 ± 8.6 | -16.5 - 9.9 |
| Mifflin [28] | 1396 ± 149 | 1240 - 1719 | -4.9 ± 7.0 | -15.0 - 5.9 |
| Bernstein [29] | 1370 ± 94 | 1273 - 1581 | -6.3 ± 8.1 | -16.6 - 7.7 |

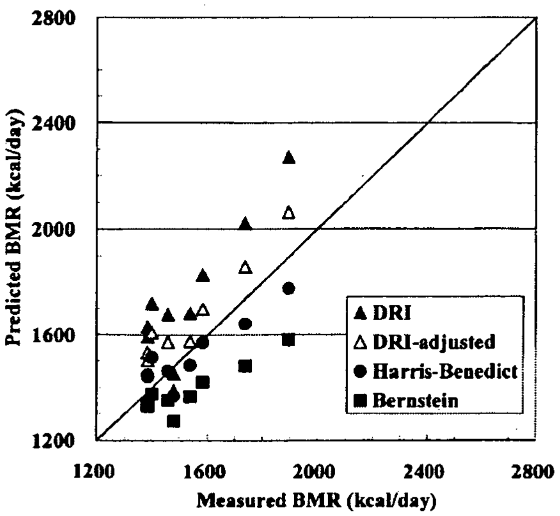


*Fig. 2.* Relationships between measured and predicted basal metabolic rate (BMR) in obese females. DRI: Japan-Dietary Reference Intakes.

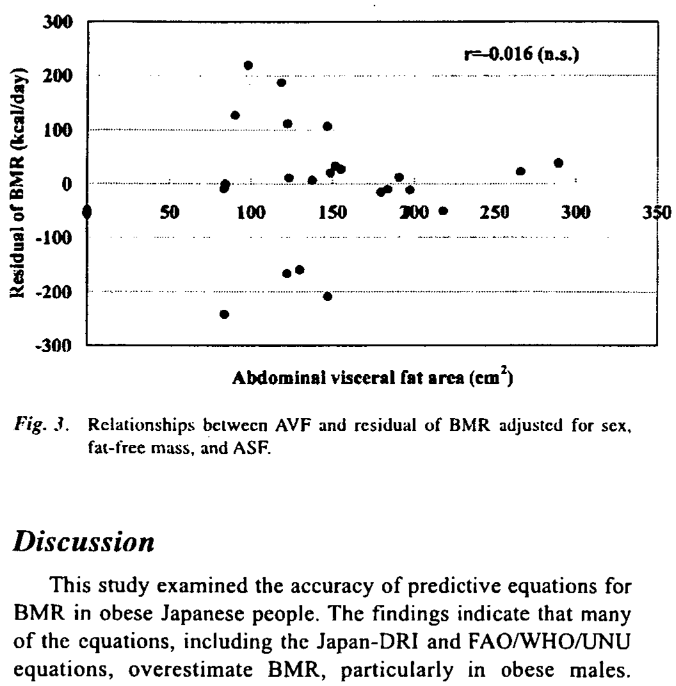


*Fig. 3.* Relationships between AVF and residual of BMR adjusted for sex, fat-free mass, and ASF.

## *Discussion*

This study examined the accuracy of predictive equations for BMR in obese Japanese people. The findings indicate that many of the equations, including the Japan-DRI and FAO/WHO/UNU equations, overestimate BMR, particularly in obese males. Similar results have been reported in many studies on Caucasians. However, several of the equations provided accurate estimates of BMR, mainly in obese females. Among the equations, the Mifflin equation in males, and the Harris-Benedict and Henry equations in females, provided a better accurate prediction of BMR.

The Japan-DRI equations are simple multiples of body weight (21.5 × body weight for males, 20.7 × body weight for females). The other equations include an intercept in addition to a term for body weight and in some cases terms for body height and age as well. Considering these differences, it is understandable that the Japan-DRI equations overestimate BMR in obese subjects of both sexes. To improve this, a term for adjustment of body weight was provided for each sex.[30] While this term reduced the overestimation of BMR, a large overestimation of BMR (12.8 ± 9.7 % for males and 8.6 ± 6.6 % for females) still remained. The suggested values for adjustment of body weight were obtained in rather lean Japanese subjects, with fat-free mass contributing considerably more to BMR than fat mass. Therefore, a low fat-free mass relative to body weight (indicated as a high percentage of body fat) may explain the overestimation, even after additional adjustment for body weight.[1] In contrast, Bernstein's equation, which was developed for obese Caucasians, underestimated BMR, especially in obese males.

The other equations incorporate an intercept, and some of them have terms for body height and age. Thus, it is expected that the terms adjust BMR for body composition to some degree, similar to BMI. However, the FAO/WHO/UNU equations that include terms for body weight and height provided comparable values to those with a term for body weight only. Considering the mean values of % difference, inclusion of terms for body height and/or age is not likely to improve the prediction of BMR in obese people, whereas the existence of an intercept or a curvilinear term would be expected to improve the predictive ability of the equation.

With the exception of the Japan-DRI equation, the predictive equations did not overestimate BMR to a large extent in obese females. This sex difference was not observed in previous studies. Female subjects in the present study had slightly higher BMI than male subjects, and their percentage body fat was also greater. While these differences should have been associated with overestimation of BMR considering the result of the present study, this can not explain the sex difference. Thus, the reason for the observed sex difference in the present study remains unclear.

The SD values of the % difference ranged from 7.4% to 12.3% in obese males and 6.6% to 9.2% in obese females. Previous studies reported that the interindividual coefficient of variation was about 8-13% in healthy people,[31,32] although interindividual variability of sleeping metabolic rate was less, at least for Japanese subjects.[9] The values calculated in the present study were within this range, but different from those of a previous study of obese subjects.[3] A possible reason for this difference may have been the uniformity of body composition, although the range of percentage body fat in the present study was large in both sexes, suggesting that this was unlikely to be the reason.

It remains controversial whether AVF is related to BMR.[10-17] Because AVF is related to sex, fat mass, and ASF, it is necessary to adjust for these variables in order to examine the relationship between AVF and BMR. In the present study, we adjusted not only for sex and fat-free mass but also for ASF to clarify the independent contribution of abdominal fat distribution. As a result, ASF but not AVF correlated independently with BMR after adjustment for sex and fat-free mass. However, this significant correlation disappeared after additional adjustment for fat mass, indicating that the independent correlation between ASF and BMR may actually reflect the relationship between fat mass and BMR. Adipose tissue has a small but definite contribution to BMR, while ASF and fat mass are correlated with each other, particularly in obese people, who have a large fat mass. If the relationship between ASF and BMR reflects the relationship between fat mass and BMR, this implies that abdominal fat distribution is not associated with BMR in obese Japanese people.

One of the limitations of the present study was the relatively small sample size. However, to obtain values of % difference when using predictive equations of BMR, the sample size used should provide relatively stable results. In the present study, normal-weight subjects were not included. To clarify the characteristics of obese subjects, this may be another problem. In addition, the analysis evaluating the contribution of abdominal fat distribution was performed in all subjects with adjustment for the effect of sex. As a consequence, comparison with the results of earlier studies could not be undertaken. Some of these previous studies reported the results for separate age categories, sex, and menopausal status.

In conclusion, the majority of the predictive equations overestimated BMR in obese Japanese males, whereas some equations were relatively accurate for obese females. In obese people, overestimated BMR may lead to overestimation of total energy expenditure. Caution is therefore needed when selecting predictive equations of BMR for obese Japanese people. Our results indicate abdominal fat distribution was not independently related to BMR.

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ORIGINAL ARTICLE

# Physical activity level in healthy free-living Japanese estimated by doubly labelled water method and International Physical Activity Questionnaire

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**Objective:** To measure total energy expenditure (TEE) for normal healthy Japanese by the doubly labelled water (DLW), and to compare the physical activity level (PAL) among categories classified by the categories used in daily reference intake (DRI), Japan and the International Physical Activity Questionnaire (IPAQ).
**Subjects and methods:** A total of 150 healthy Japanese men and women aged 20- to 59-year-old living in four districts of Japan. TEE was measured by the DLW method, and the PAL was calculated from TEE divided by basal metabolic rate. Simultaneously with TEE measurement, the PAL was assessed employing the categories used in DRI, Japan and IPAQ.
**Results:** The average TEE and PAL were $10.78 \pm 1.67$ MJ/day and $1.72 \pm 0.22$ for males and $8.37 \pm 1.30$ MJ/day and $1.72 \pm 0.27$ for females, respectively. The subjects in the highly active categories assessed by both DRI and IPAQ showed significantly higher PAL compared with less active categories. However, PALs among light and moderate categories by DRI, and insufficient and sufficiently active by IPAQ were not significantly different.
**Conclusions:** In developed countries, highly active subjects could be assessed by a simple questionnaire. However, the questionnaire should be improved to clarify the sedentary to moderately active subjects by assessing carefully very light to moderate physical activity.
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**Keywords:** doubly labelled water; energy expenditure; physical activity; assessment; questionnaire

## Introduction

Assessment of total energy expenditure (TEE) is essential for establishing dietary reference intakes (DRI) and recommendations for physical activity. The doubly labelled water (DLW) method is recognized as the gold standard for measuring TEE in free-living conditions (Montoye *et al.*, 1996). Many studies using the DLW method have been performed, mainly in developed countries (Schulz *et al.*, 1994; Black *et al.*, 1996; Prentice *et al.*, 1996; Westerterp, 2003; Brooks *et al.*, 2004). However, the physical activity level (PAL) calculated as TEE divided by the basal metabolic rate (BMR) is expected to be different among populations with different lifestyles. The typical lifestyle of healthy

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