Original Article

The Use of a Uniaxial Accelerometer to Assess Physical-activity-related Energy Expenditure in Obese Men and Women: Saku Control Obesity Program (SCOP)

Motohiko Miyachi 1), Yumi Ohmori 1), Kenta Yamamoto 2), Hiroshi Kawano 2), Haruka Murakami 1), Akemi Morita 1), Shaw Watanabe 1)

1) National Institute of Health and Nutrition
2) Waseda University

Abstract

INTRODUCTION: Energy expenditure (EE) associated with physical activity is negatively correlated with prevalence of obesity and related diseases, and exercise plays a major role in prevention and treatment of these diseases. We determined baseline daily step-count and physical activity-related energy expenditure (PAEE) in 230 obese subjects (40–64 years old) participating in the Saku Control Obesity Program. The secondary purpose of this study was to determine the association between abdominal fat and amount of physical activity.

METHODS: Daily step-count and PAEE were measured using a uniaxial accelerometer. The subjects wore the uniaxial accelerometer on their belt from the time they woke up until going to bed for 2 weeks. Adjusted PAEE (METs/h/day) was calculated based on daily PAEE and body weight.

RESULTS AND CONCLUSIONS: Daily step-count, PAEE, and adjusted PAEE were 7,815±3,211 (mean±SD) steps/day, 258±115 kcal/day, and 3.09±1.38 METs/h/day, respectively. There were no significant differences in daily step-count or adjusted PAEE between men and women. Daily step-count and adjusted PAEE were somewhat lower than the reference values for the quantity of physical activity for health promotion (8,000-10,000 steps/day and 3.3 METs/h/day) established by the Ministry of Health, Labour, and Welfare of Japan. BMI, visceral fat area, and abdominal circumference were negatively and weakly correlated with daily step-count and adjusted PAEE (r=−0.13 to -0.19, P=0.05 to 0.01). These results suggest that the amount of physical activity assessed by uniaxial accelerometer is partially associated with not only systemic obesity but also abdominal obesity.

KEYWORDS: accelerometer, energy expenditure, daily step-count, obesity, physical activity

Introduction

The energy expenditure (EE) associated with physical activity is negatively correlated with the prevalence of obesity and related diseases, such as diabetes, hypertension, and cardiovascular disease, and exercise has been shown to play a major role in the prevention and treatment of these diseases.1,3) When developing treatment strategies for these diseases, including nutritional education, quantitative information related to physical activity is required to provide more effective goals. Thus, to prevent and treat these diseases more effectively, information regarding physical activity is useful, not only for researchers and healthcare workers but also for the general public.

Activity monitoring based on an accelerometer sensor is a useful method for obtaining objective information on physical activity patterns and for estimating the related EE,4,5) because this type of sensor (Lifecorder; Suzuken Co. Ltd., Nagoya, Japan) can continuously measure the intensity, duration, and frequency of activity. The device has a unique algorithm for assessment of PAEE, especially unstructured activities. In addition, several studies indicated that the EE during running and walking estimated using this device correspond to the EE measured by indirect calorimetry, and the device was also more effective for measuring EE in free-living conditions as compared with a metabolic chamber.6,7)

Increasing physical activity and decreasing caloric intake are indispensable for the improvement of excess weight and obesity. The Saku Control Obesity Program (SCOP) is a randomized control crossover study that aims to reduce visceral fat in overweight and obese subjects by interventions of physical activity and diet. Our systematic review suggested that an increase in adjusted PAEE at 10 METs/h/week (1.38 METs/h/day) is necessary to reduce visceral fat area in overweight and obese subjects.9) The increase in adjusted PAEE corresponds to an increase of nearly 3,000 steps/day. Thus, all SCOP subjects receive physical activity modification education so that their daily step-count increase gradually by 3,000 steps/day. As each subject’s target for modification of physical activity depends on the baseline level, accurate baseline measurements of physical activity are needed. The first purpose of the present study was to accurately determine the baseline status of physical activity using a uniaxial accelerometer. Furthermore, there have been few studies of the relationship between abdominal obesity and physical activity. Therefore, the second purpose of this study was to determine the association between visceral fat area measured by CT scan and amount of physical activity estimated by accelerometry.
Methods

Each year about 7,000 examinees came to the Saku Health Doc Center for health checkups. Including all visits, the Saku Health Doc Center database contains approximately 197,000 records. We used the database to select initial examination records, and about 45,000 examinees were identified. For this study, the inclusion criteria were age 40–64 years and a body mass index (BMI; kg/m²) within the upper quintile (28.3). Exclusion criteria were psychiatric conditions or physical conditions (i.e., significant hepatic or renal dysfunction and significant cardiovascular disease such as heart failure, stroke, and transient ischemic attacks) that would preclude full participation in the study; current treatment for obesity; current treatments known to affect eating or weight (e.g., medications). A total of 917 people whose BMI was more than 28.3 (upper quintile) were identified in the health checkup database, and 235 participants were enrolled in the Saku Control Obesity Program (SCOP). 16

Five subjects who did not wear the accelerometer for 7 days or more were excluded from the study. Of the remaining 230 subjects, 111 were male and 119 were female. All research procedures of SCOP were performed according to the Helsinki Declaration. All subjects gave their written informed consent to participation in the study, and all procedures were reviewed and approved by the Ethical Review Board of the National Institute of Health and Nutrition.

To determine the baseline values of physical activity, each subject wore a uniaxial accelerometer on his or her belt from the time of waking to going to bed for 2 weeks. Measurements were as follows: daily step-count; PAEE; adjusted PAEE for body weight; and time spent in light, moderate, and vigorous physical activity. As the daily physical activities varied across the measurement period, daily mean values were calculated.

The activity monitor measures acceleration in the vertical direction. According to technical details provided by the manufacturer (Suzuka Co., Ltd.), it samples the acceleration at 32 Hz and assesses values ranging from 0.06 to 1.94 g (where 1.00 g is equal to the acceleration of free fall). The acceleration signal is filtered by an analog band-pass filter and digitized. The frequency of acceleration signals is used to determine the step frequencies. Studies have shown that during walking the step frequencies measured by the accelerometer are within ±3% of the actual number of steps.10 A maximum pulse over 4 s is taken as the acceleration value, and the activities are categorized into 11 activity levels based on the pattern of the accelerometer signal. The activity levels are subsequently converted by an algorithm to calculate EE (kcal) based on the following principle: when the sensor detects or more three acceleration pulses for 4 consecutive seconds, the activities are recognized as physical activity and are categorized into one of 9 activity levels (levels 1.0–9.0). The activity levels are calculated and counted every 4 s. The activity levels for ranges from 1.0 to 9.0 in steps of one unit corresponded to 1.465, 2.075, 2.808, 3.601, 4.537, 5.737, 7.324, 9.460, and 10.661 cal/kg/4 s, respectively.7 There was a strong correlation between the activity levels and the measured EE while walking (r²=0.93; P<0.001).7 The daily PAEE (kcal) was calculated by summing the EE corresponding with activity levels every 4 s (cal/kg/4 s) and the product of the body weight (kg) of each subject.

If an acceleration pulse due to physical activity (i.e., corresponding to activity levels 1.0–9.0) is not followed immediately by another acceleration pulse, it is not counted as 0.0 but level 0.5 is arbitrarily assigned for 3 min. It is assumed that the subject is standing up (or sitting down) and remaining in that state. These postures involve a higher EE than the resting supine position. Briefly, isolated spurs of acceleration are assumed to be due to acute changes in posture (lying down, sitting, and standing), because walking and moving around are typically rhythmic activities. EE due to very small trunk movements and posture effects (e.g., changing from sitting to standing position, light deskwork) were not included in the PAEE. Thus, the PAEE measured by the accelerometer was systematically underestimated during a 24-h period, and the accelerometer assessed energy expenditure well during both the exercise period and the non-structued activities.17

As the PAEE is associated with body weight, PAEE adjusted for body weight (adjusted PAEE) was calculated as follows: adjusted PAEE (METs·h)=PAEE (kcal)/(W (kg) × 1.05).11 The various activity levels are categorized as light (<3.0 METs), moderate (3.0–6.0 METs), and vigorous (>6.0 METs), and the time spent in each activity category per total time of physical activity (%) was calculated. In addition, the time spent in sedentary activity (sitting at a desk, visiting friends, reading, or watching television) was obtained from subjects’ answers to the International Physical Activity Questionnaire (IPAQ).12

Anthropometric measurements (height, weight, and abdominal circumference) were determined in the standing position after the subjects removed their clothes, shoes, and socks. Abdominal circumference as a surrogate measurement of abdominal obesity was measured at the level of the umbilicus during expiration. Abdominal fat distribution was determined with subjects in the supine position using CT according to the procedure described previously.13 Visceral fat areas were measured on one cross-sectional scan obtained at the umbilicus.

All statistical analyses were performed using SPSS® software (version 14.0; SPSS Inc., Chicago, IL, USA). All data are shown as means ± standard deviation. The differences between groups were analyzed by unpaired t-test. Linear regressions and Pearson’s correlation coefficients were calculated. In addition, stepwise regression analysis was performed. Statistical significance was set at P<0.05.

Results

The subjects’ characteristics are listed in Table 1. Although there were no significant differences in age or BMI between men and women, height, body weight, and abdominal circumference in men were significantly greater than those in women. Using the Japanese diagnostic criteria, the prevalence of metabolic syndrome was 62.9% in men and 51.3% in women. These values

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subject characteristics at baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>Total (n=235)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>53.9±6.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.8±8.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.7±12.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>30.8±3.4</td>
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<tr>
<td>Abdominal circumference (cm)</td>
<td>106±9</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>138±19</td>
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<tr>
<td>DBP (mmHg)</td>
<td>85±14</td>
</tr>
<tr>
<td>FPG (mg/dL)</td>
<td>113±26</td>
</tr>
<tr>
<td>TG (mg/dL)</td>
<td>158±84</td>
</tr>
<tr>
<td>HDL-cholesterol (mg/dL)</td>
<td>53±11</td>
</tr>
<tr>
<td>Visceral fat area (cm²)</td>
<td>144±53</td>
</tr>
</tbody>
</table>

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TG, triglyceride; HDL, high density lipoprotein

*p < 0.05 vs. men
### Table 2  Daily physical activity at baseline

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total (n=230)</th>
<th>Men (n=111)</th>
<th>Women (n=119)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. steps (steps/day)</td>
<td>7815 ± 3211</td>
<td>7601 ± 3300</td>
<td>8015 ± 3127</td>
</tr>
<tr>
<td>PAEE (kcal/day)</td>
<td>258 ± 115</td>
<td>271 ± 127</td>
<td>246 ± 102*</td>
</tr>
<tr>
<td>Adjusted PAEE (METs-h/week)</td>
<td>3.09 ± 1.38</td>
<td>3.03 ± 1.43</td>
<td>3.15 ± 1.35</td>
</tr>
<tr>
<td>Time spent in light PA (%)</td>
<td>77.2 ± 12.2</td>
<td>76.1 ± 12.2</td>
<td>78.2 ± 12.2</td>
</tr>
<tr>
<td>Time spent in moderate PA (%)</td>
<td>21.5 ± 11.0</td>
<td>23.0 ± 11.9</td>
<td>20.0 ± 9.9*</td>
</tr>
<tr>
<td>Time spent in vigorous PA (%)</td>
<td>1.1 ± 1.4</td>
<td>0.9 ± 1.1</td>
<td>1.2 ± 1.5</td>
</tr>
<tr>
<td>Time spent in sedentary activity (min/day)</td>
<td>381 ± 230</td>
<td>436 ± 247</td>
<td>324 ± 188*</td>
</tr>
</tbody>
</table>

PAEE: physical-activity-related energy expenditure; METs, metabolic equivalents; PA, physical activity
* : p < 0.05 vs. men

The physical activity properties at baseline (i.e., daily step-count, PAEE, adjusted PAEE, and time spent in light, moderate, and vigorous physical activity) are shown in Table 2. The daily PAEE was significantly larger in men as compared with women. The time spent in moderate physical activity was longer in men than in women. In contrast, the time spent in sedentary activity in women was significantly shorter than that in men. There were no significant differences in other physical activity parameters between men and women. Although the association between occupation and PAEE was examined, there were no significant differences among the occupational categories (data not shown).

In all subjects, the daily step-count was closely related to the daily PAEE (r=0.92, P<0.001) and adjusted PAEE (r=0.99, P<0.001). The daily step-count was positively associated with the time spent in moderate physical activity (r=0.35, P<0.001), but negatively associated with time spent in light physical activity (r=-0.30, P<0.001). BMI was negatively correlated with the daily step-count (r=-0.13, P<0.05) and adjusted PAEE (r=-0.14, P<0.05). Moreover, body weight was negatively correlated to the daily step-count (r=-0.19, P<0.01, Figure 1, top) and adjusted PAEE (r=-0.18, P<0.01, Figure 1, middle).

Visceral fat area was negatively and significantly correlated to the daily step-count (r=-0.14, P<0.05, Figure 2, top) and adjusted PAEE (r=-0.15, P<0.05, Figure 2, bottom). Abdominal

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**Fig. 1** Relationships between body weight and daily step-count (upper), adjusted physical activity-related energy expenditure (middle), and time spent in sedentary activity (bottom).

**Fig. 2** Relationships between visceral fat area and daily step-count (upper), adjusted physical activity-related energy expenditure (middle), and time spent in sedentary activity (bottom).
circumference as a surrogate measurement of abdominal obesity was negatively and significantly related to the daily step-count ($r = -0.14, P < 0.05$) and adjusted PAEE ($r = -0.16, P < 0.05$). However, body weight had positive and significant correlations with daily PAEE ($r = 0.15, P < 0.05$) and the time spent in sedentary activity ($r = 0.14, P < 0.05$, Figure 1, bottom). If all activities were weight-bearing, the PAEE would only be expected be directly related to body weight.

Stepwise regression analysis showed that the daily step-count could be adopted as an independent variable for BMI and body weight, and adjusted PAEE could be adopted as an independent variable for visceral fat area and abdominal circumference.

**Discussion**

The main findings of this descriptive study were as follows. First, the mean daily step-count was 7,815 steps in all SCOP subjects, with no difference between men (7,601 steps) and women (8,015 steps). Second, the adjusted PAEE for body weight was 3.09 METs/h/day in all subjects, and there was no sex-related difference. The adjusted PAEE was somewhat smaller than the reference values for the quantity of physical activity for primary prevention of lifestyle-related diseases (3.3 METs/h/day) established by the Ministry of Health, Labour, and Welfare of Japan. Third, the amount of physical activity (daily step-count and adjusted PAEE) was significantly and negatively related to body size (body weight and BMI) and abdominal fat (visceral fat area and abdominal circumference) in the pooled subjects, although the correlation coefficients were weak ($r = -0.1$ to –0.2).

Average daily step-count in Japanese men is generally greater than that in Japanese women as assessed by a national health and nutrition survey.

In the present study, the daily step-count in female subjects was about 1,400 steps/day greater than that in male participants. The unexpectedly higher daily step-count in the female subjects may be related to their slower walking speed and shorter stride than the male subjects. In fact, the time spent in moderate physical activity (brisk walking) by women was significantly shorter than that by men, and the time spent in light physical activity (slow walking) tended to be longer in women as compared with men.

In 2006 the Ministry of Health, Labour, and Welfare reexamined the recommended quantity of exercise for primary prevention of lifestyle-related diseases (originally proposed in 1989) and set reference values for the quantity of physical activity and exercise for Japanese people between the ages of 20 and 69 years. Specifically, for individuals who intend to promote health mainly through physical activity, walking 8,000 to 10,000 steps/day (23 METs/h/week) was set as the target daily amount of physical activity. In the present study, the daily step-count and adjusted PAEE for body weight were 7,815 steps/day and 3.09 METs/h/day, respectively, which were somewhat lower than the reference values described above.

Several previous studies from the USA and UK indicated that daily step-counts in overweight and obese adults are lower than those in normal-weight peers. The present study showed that adjusted PAEE and daily step-count were significantly and negatively correlated with visceral fat and abdominal circumference in the pooled overweight and obesity subjects. This is the first evidence that the amount of physical activity is partly associated with not only systemic obesity but also abdominal obesity. Furthermore, in accordance with the results of stepwise regression analysis, although daily step-count was an independent predictor of weight and BMI, adjusted PAEE was an independent predictor of abdominal obesity, i.e., visceral fat area and abdominal circumference. As adjusted PAEE is determined by the duration and intensity of physical activity, accumulation of abdominal fat may be associated with not only the duration but also the intensity of physical activity. We should emphasize that the relationships between amount of physical activity and obesity variables were weak ($r = -0.1$ to –0.2). This implies that factors other than physical inactivity (e.g., overeating) may strongly contribute to obesity in the SCOP subjects. To clarify the cause of obesity in SCOP subjects, the results from the uniaxial accelerometer should be compared with the responses to dietary history questionnaires.

Increasing physical activity and reducing caloric intake are indispensable for the improvement of excess weight and obesity. SCOP is a randomized control crossover study aiming to reduce visceral fat of overweight and obese subjects by interventions of physical activity and diet. Our systematic review suggested that an increase in adjusted PAEE at 10 METs/h/week (1.38 METs/h/day) is necessary to reduce visceral fat of overweight and obese subjects. The increase in daily step-count corresponds to an increase of almost 3,000 steps/day as compared with the baseline. Therefore, all SCOP subjects receive physical activity modification education so that their daily step-count increases gradually by 3,000 steps/day, and it is necessary to set the mean value of action targets for 11,000 steps/day and 4.5 METs/h/day.

The validity and reliability of the uniaxial accelerometer have been established. One methodological limitation, however, is that a uniaxial accelerometer cannot measure very light physical activity ($<1.8$ METs). Daily life includes a great deal of very light physical activity, and very light PAEE occupies more than the half of total PAEE. Therefore, we should emphasize that the PAEE obtained in the present study was not total PAEE but PAEE at 2 METs intensity or more. Moreover, the cross-sectional study design is another limitation of the present study. The results of the present cross-sectional study must be confirmed prospectively with exercise intervention studies in future.

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