表4　性，年代別の運動習慣の有無による閉眼片足立ち（秒）の比較

男性

年代	運動習慣（+）		運動習慣（−）		p
	平均値±標準偏差	120秒達成者数	平均値±標準偏差	120秒達成者数	
20～29	54.2 ± 39.6	28（14.8%）	50.5 ± 40.1	75（16.0%）	0.2883
30～39	45.7 ± 37.4	20（10.1%）	38.7 ± 33.9	34（6.3%）	0.0157
40～49	36.7 ± 32.0	6（3.2%）	30.6 ± 28.0	9（2.6%）	0.0230
50～59	23.1 ± 25.3	2（1.4%）	22.1 ± 21.8	2（2.2%）	0.6729
60～69	15.0 ± 14.7	0（0.0%）	11.3 ± 10.5	0（0.0%）	0.0547

女性

年代	運動習慣（+）		運動習慣（−）		p
	平均値±標準偏差	120秒達成者数	平均値±標準偏差	120秒達成者数	
20～29	56.5 ± 42.8	52（19.0%）	47.7 ± 38.2	171（12.6%）	0.0007
30～39	47.1 ± 38.0	23（9.0%）	43.5 ± 36.5	98（8.1%）	0.1600
40～49	34.4 ± 30.1	11（3.3%）	31.5 ± 29.1	32（3.6%）	0.1189
50～59	24.4 ± 25.3	11（3.2%）	21.6 ± 22.5	7（1.1%）	0.0836
60～69	11.6 ± 14.3	2（0.8%）	11.4 ± 13.6	1（0.4%）	0.8601

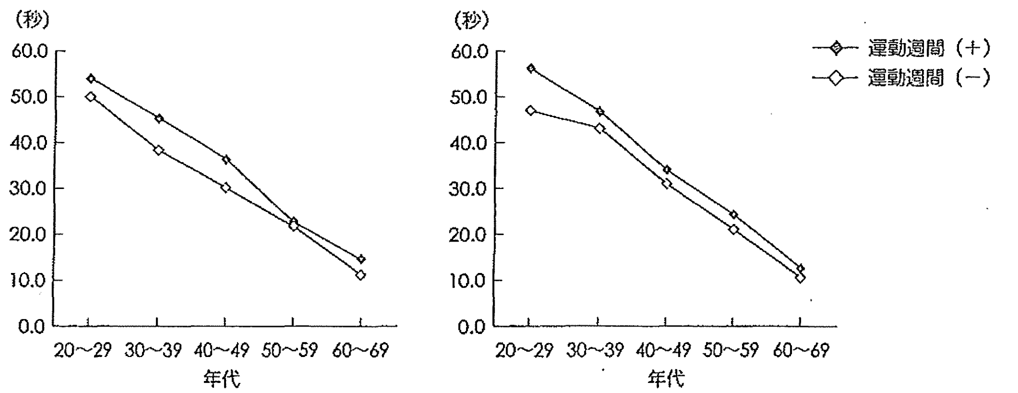

図1　性，年代別の運動習慣の有無による閉眼片足立ち（秒）の比較

歳代で最高値を示し，その後，加齢とともに直線的に低下していた．樋口ら[8]も，20～85歳の健常男女1,028人の測定を行ない，連続的な測定値の低下を認め，60歳以上では平均値は10秒を下回っていたと報告している．開眼片足立ちの場合，多くの被験者が最長時間を達成することが多く[9]，閉眼片足立ちの方を，開眼片足立ちよりも推奨している報告もある[10]．一方，高齢者の転倒リスクとの関連では開眼片足立ちを推奨している報告もあり[11]一定の見解は得られていない．今回の調査では，加齢に伴い閉眼片足立ちの有意な低下が認められた．従来の報告値では，ばらつきが多いと報告されているが[12]，加齢に伴いさまざまな病気をもつ人が増え，体力に影響を及ぼすこ

とは容易に予想されることから，今回の健常人での閉眼片足立ちの結果は，日本人における平衡機能の参考値のひとつになるものと思われた．

今回のもうひとつの特徴は，運動習慣の有無による閉眼片足立ちを比較したことである．国民健康・栄養調査での運動習慣の定義は，1回30分，週2回，1年以上継続となっており，今回の調査では継続期間が3カ月とやや短くなっているものの，国民健康・栄養調査の結果とほぼ同様の結果で，加齢に伴い運動習慣者の割合が増加していた．また，運動習慣の有無によって性，年代別に閉眼片足立ちを比較すると，男性の30歳代，40歳代，女性の20歳代でのみ運動習慣のある人がない人に比較して閉眼片足立ちの値が高値を示した．男女とも60歳代では運動習慣のある割合は高いものの，強度，時間は若年者に比較すると低く，短いものであることが予想されるため，運動習慣の影響が高齢者では出にくかったのではないかと思われた．さらに，全身持久力など他の体力の指標に比較すると運動習慣自体の影響が比較的少ないのではないかと思われた．

今後は，全身持久力，筋力と同様に平衡機能と疾病，転倒危険度との関連，さらには生命予後との関連を検討していくことが必要であろう．

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Long-term Detraining Increases the Risk of Metabolic Syndrome in Japanese Men

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Objective: The aim of the present study was to examine the effect of long-term detraining on metabolic syndrome (MetS).
Methods: 1109 Japanese men were categorized by their exercise habits. Clinical data, number of MetS risk factors, and differences in lifestyle-related behaviors of the non-training group (n = 233) and the detraining group (n = 483) were compared with those of the training group (n = 87).
Results: Waist circumference and body mass index were significantly higher in the non-training group and the detraining group than in the training group, and also higher in the detraining group than in the non-training group. High-density lipoprotein cholesterol (HDL-C) was lower and low-density lipoprotein cholesterol (LDL-C) was higher in the non-training group and the detraining group than in the training group. Both the non-training group and the detraining group had more MetS risk factors than the training group. The odds ratio for smoking was higher in the detraining group than in the training group.
Conclusions: Detraining results in similar degrees of obesity, low HDL-C, high LDL-C, and high MetS risk as non-training. To prevent lifestyle-related diseases, it is particularly important not only to encourage adults to become physically active, but also discourage active young people from discontinuing physical exercise.

Key words: metabolic health, exercise, health behavior, older adults, youth

INTRODUCTION

It is well known that habitual exercise has beneficial effects on health. In addition to amelioration of obesity [1-5], there is ample evidence to show that exercise can prevent or ameliorate risk factors for cardiovascular disease (CVD) such as type 2 diabetes [6-9], hypertension [10, 11], and dyslipidemia [12-16]. Metabolic syndrome (MetS) is characterized by increased insulin resistance associated with central obesity and clustering of metabolic risk factors, including impaired glucose tolerance, hypertension, and dyslipidemia. In order to prevent or ameliorate MetS, it is important to remain physically active [17, 18].

Some people discontinue habitual exercise even though they had exercised regularly during their student days. However, little is known about the effects of long-term detraining on health. It has been reported that short-term detraining (several days to weeks) has negative effects on lipid metabolism, such as increased triglyceride (TG) [19] and decreased high-density lipoprotein cholesterol (HDL-C) [20-23]. Moreover, relatively longer-term detraining (several years) has been reported to increase body mass index (BMI) and adiposity [24, 25], exacerbate lipid metabolism, and decrease bone mineral density [26, 27]. As to the effects of long-term detraining, or detraining for several decades since youth, there has been only one report on the risk of fractures in men [28] but no report focusing on MetS risk factors.

In the present study, in order to examine the effect of long-term detraining on MetS, 1109 Japanese men were categorized into four groups according to their exercise habits (training group, non-training group, detraining group, and others), and the clinical data and numbers of MetS risk factors of the non-training group or the detraining group were compared with those of the training group.

METHODS

Subjects

Of 1467 men who underwent annual health checks at the Health Planning Center at Makita General Hospital between February and March 2007, 1109 men aged 40-74 years, excluding those who were already treated for hypertension, dyslipidemia, or diabetes, were selected. Medical history was surveyed using a self-administered questionnaire. Habitual exercise dur-

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ing the student days (from primary school to college) was defined as maintaining physical activity ≥ 2 hours a day more than three times a week. Present habitual exercise was defined as maintaining physical activity ≥ 30 min a day more than once a week. Information about exercise habits was obtained through an interview. The subjects were categorized into four groups according to their exercise habits. The training group consisted of individuals who were continuing habitual exercise from youth to the present. The non-training group consisted of those who never had a habit of exercise, while the detraining group consisted of subjects who had exercised regularly during their student days but not at present. Finally, the others group consisted of individuals with other exercise habits. In this study, the clinical characteristics of the detraining group were compared with those of the training group or the non-training group. This study was designed in compliance with the ethics regulations outlined in the Declaration of Helsinki. Anonymized health records were used for analysis, and the privacy of participants was completely protected by unlinkable anonymization.

Measurements and definition of MetS

Anthropometric measurements were performed, and blood samples were obtained after overnight fasting. All measurements were included in the routine health check examinations. BMI was calculated by dividing weight (kg) by height squared (m^2). Waist circumference (WC) was accurately assessed by a trained staff member at the end of expiration in the standing position, measuring the minimum circumference at the level of the umbilicus to the nearest 0.5 cm. Blood pressure was measured at the right upper arm in a sitting position. Glycosylated hemoglobin (HbA1c) was measured by a high performance liquid chromatography (HPLC) method. The value for HbA1c (%) was estimated as a National Glycohemoglobin Standardization Program (NGSP) equivalent value (%) calculated by the formula HbA1c (%) ≈ HbA1c (Japan Diabetes Society, JDS) (%) + 0.4%, considering the relational expression of HbA1c (JDS) (%) measured by the previous Japanese standard substance and measurement methods and HbA1c (NGSP) [29]. Serum lipid levels were measured enzymatically. The following cut-off values were used according to the Japanese definition of MetS [30]: WC ≥ 85 cm, hypertension (systolic blood pressure (BP) ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg), FPG ≥ 110 mg/dl, triglyceride (TG) ≥ 150 mg/dl, and/or high-density lipoprotein cholesterol (HDL-C) < 40 mg/dl. The presence of WC ≥ 85 cm and two or more of the other risk factors constitutes a diagnosis of MetS. Information about lifestyle-related behaviors, including smoking, snacking, and drinking alcohol (≥ 50 g/day), was obtained using a questionnaire.

Statistics

Data are expressed as means ± SD. StatView-J 5.0 (Statistical Analysis System Inc, Cary, NC, USA) was used for the statistical analyses. Significant differences in age and clinical data among the three groups were evaluated using Scheffe's multiple comparison test. Odds ratios (*OR*) and 95% confidence intervals (CI) were calculated for WC ≥ 85 cm, BMI ≥ 25 cm/m^2, the presence of MetS, and the differences in lifestyle-related behaviors, using the training group as the reference. The numbers of MetS risk factors (hypertension, dyslipidemia, and hyperglycemia) were compared by ridit analysis [31] using the training group as the standard. All p values were two-tailed, and $p < 0.05$ was considered significant.

RESULTS

Table 1 shows the categorization of the groups by exercise habits. The 1109 Japanese men were categorized as follows: training group ($n = 87$), detraining group ($n = 483$), non-training group ($n = 233$), and others ($n = 306$). Those who had not exercised during their student days but started exercise thereafter were included in the others ($n = 72$). The ages ($M \pm SD$) of those in the training, non-training, and detraining groups were 50.8 ± 7.7, 51.4 ± 7.2, and 49.2 ± 7.1 years, respectively. Overall, 93% of the subjects in the detraining group had exercised regularly until they were college students, which indicates that most of them discontinued exercise after they started working. The frequency of present physical activity in the training group was as follows: once a week (36%), twice a week (13%), 3 times a week (19%), 4 times a week (2%), and ≥ 5 times a week (30%).

Since part of their BMI data when they were 20 years of age were available, we have analyzed the data as below.

training group ($n = 56$; 64% of total, $M = 20.9$, $SD = 1.6$)

detraining group ($n = 360$; 75% of total, $M = 21.3$, $SD = 2.6$)

non-training group ($n = 144$; 62% of total, $M = 21.1$, $SD = 2.6$)

There were no statistical differences among all the groups by Scheffe's multiple comparison tests.

The clinical characteristics according to exercise habits are shown in Table 2. WC and BMI were significantly higher in the non-training and the detraining groups than in the training group. Moreover, the detraining group had a significantly higher WC and BMI than the non-training group. HDL-C was significantly lower and low-density lipoprotein cholesterol (LDL-C) was significantly higher in the non-training and the detraining groups than in the training group. TG and total cholesterol (TC) tended to be higher in the non-training and the detraining groups than in the training group. Table 2 illustrates the numbers of MetS risk factors present according to exercise habits. On ridit analysis, the values of the mean ridit for the non-training group (0.616, $p < 0.01$) and the detraining group (0.596, $p < 0.01$) were significantly higher using the training group as the standard (mean ridit: 0.5). The result of ridit analysis demonstrated that both the non-training and the detraining group had significantly more MetS risk factors than the training group. However, there was no difference between the non-training group and the detraining group on ridit analysis.

The *OR*s and 95% CIs for the presence of obesity and MetS, and differences in lifestyle-related behaviors are shown in Table 3. The *OR*s for WC ≥ 85 cm, BMI

Table 1 Categorization of the groups according to exercise habits

	Exercise habits		Subjects	
Category	Student days	Present	*n*	(%)
Training	≥ 2 hours/day and ≥ 3 times/week	≥ 30 mins/day and ≥ once/week	87	(7.8)
Non-training	none	none	233	(21.0)
Detraining	≥ 2 hours/day and ≥ 3 times/week	none	483	(43.6)
Others	any other patterns of exercise habits		306	(27.6)
Total			1109	(100)

Table 2 Comparison of clinical characteristics by exercise habits

	Training	Non-training	Detraining
WC (cm)	81.1 ± 5.7	86.8 ± 9.9**	88.8 ± 8.4**,#
BMI (kg/m^2)	22.8 ± 2.2	24.0 ± 3.7*	24.9 ± 3.3**,##
SBP (mmHg)	125.8 ± 16.9	130.1 ± 18.0	128.8 ± 17.2
DBP (mmHg)	74.8 ± 11.1	78.0 ± 11.3	77.3 ± 12.3
FPG (mg/dl)	104.4 ± 17.0	109.7 ± 23.7	109.0 ± 24.0
HbA1c (%)	5.6 ± 0.5	5.8 ± 1.0	5.8 ± 0.9
TG (mg/dl)	122.9 ± 134.3	137.0 ± 86.3	145.5 ± 108.2
HDL-C (mg/dl)	64.6 ± 16.5	59.1 ± 16.6*	58.1 ± 14.5*
LDL-C (mg/dl)	134.7 ± 33.2	147.6 ± 36.7*	147.8 ± 37.8*
TC (mg/dl)	202.1 ± 33.4	209.2 ± 33.1	209.4 ± 35.2
No. of MetS risk factors			
0	35 (40%)	61 (26%)	137 (28%)
1	35 (40%)	84 (36%)	176 (36%)
2	14 (16%)	61 (26%)	133 (28%)
3	3 (3%)	27 (12%)	37 (8%)
Mean ridit	0.500	0.616**	0.596**

Data are M ± *SD* or *n* (%). BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol
*: $p < 0.05$, **: $p < 0.01$ relative to training group, #: $p < 0.05$, ##: $p < 0.01$ relative to non-training group (Scheffe's multiple comparison test)

Table 3 Odds ratios and 95% confidence intervals for WC ≥ 85 cm, BMI ≥ 25 kg/m^2, the presence of metabolic syndrome (MetS) and the differences in lifestyle-related behaviors

	Non-training	Detraining
WC ≥ 85 cm	5.98 (3.34 – 10.70)	10.30 (5.91 – 17.96)
BMI ≥ 25 kg/m^2	6.94 (3.06 – 15.70)	9.02 (4.08 – 19.93)
MetS	3.82 (1.75 – 8.35)	4.28 (2.02 – 9.08)
Smoking	1.32 (0.78 – 2.25)	2.01 (1.23 – 3.29)
Snacking	1.33 (0.68 – 2.60)	1.88 (0.93 – 3.78)
Drinking (≥ 50 g/day)	1.64 (0.78 – 9.43)	1.88 (0.93 – 3.78)

The training group was used as the reference

≥ 25 kg/m², and the presence of MetS were significantly higher in both the non-training and the detraining group in contrast to the training group (referent group). Compared with the training group, the *OR* for smoking was significantly higher in the detraining group. Although the detraining group showed higher *OR*s compared with the non-training group, there were no significant differences in *OR*s for snacking and drinking alcohol (≥ 50 g/day).

DISCUSSION

In subjects undergoing regular health check-ups, the influence of long-term habitual exercise on MetS was evaluated. While other studies examining the effects of detraining on MetS risk factors have been limited to a few years of detraining, the present study is the first to examine the effects of detraining over several decades, starting from student days. The prevalence of obesity and MetS was significantly increased in the detraining group (discontinued exercise), compared to the training group (continued exercise). In other words, detraining led to obesity to the same extent as in the non-training group, and the risk of MetS was clearly increased.

Since this study was a cross-sectional study, all of the subject s data from their school days were not available. However, the analysis of more than 60% of subject s BMI data when they were 20 years old indicated that there were no statistical differences among all the groups by Scheffe s multiple comparison tests. These results suggested that although their BMI were almost same when they are 20, BMI has changed afterward probably due to their different excise habits.

MetS risk factors include obesity, impaired glucose tolerance, hypertension, and dyslipidemia (high TG and low HDL-C). In the present study, changes in obesity and HDL-C were noted. WC and BMI, indicators of central and overall obesity, respectively, were both increased with detraining in comparison to the training as well as the non-training groups. WC measurements can vary greatly depending on the examiner, but in the present study, a single pre-trained examiner took all measurements, thus ensuring highly reliable data. With detraining, obesity progressed due to a decrease in energy expenditure, but a questionnaire was used to confirm whether there were also other changes in lifestyle habits. The results showed no differences in frequency of snacking or drinking alcohol.

The effects of aerobic exercise on lipid metabolism (TG, HDL-C, TC, and LDL-C) have been reported in several subject populations. For example, in healthy males aerobic exercise decreased TC and TG and increased HDL-C [12], in obese subjects it decreased TG [14], in elderly subjects (age ≥ 50 years) it decreased TC and LDL-C and increased HDL-C [15], and in CVD patients aerobic activity decreased TG and increased HDL-C [16]. On the other hand, increases in TG [19] and decreases in HDL-C [21–23] have been observed within a short period of a few days to few weeks of detraining. The reason for this is thought to be a loss in the enhanced activity of lipoprotein lipase provided by exercise [20, 21]. In our study, HDL-C significantly decreased, and LDL-C significantly increased in the non-training and the detraining groups compared to the training group.

In the present study, habitual exercise during student days was defined as physical activity ≥ 2 hours a day at least 3 days a week, and present habitual exercise was defined as physical activity ≥ 30 minutes a day at least once a week. This was done because, among respondents who regularly exercised during school days, exercise frequency was ≥ 3 days a week in 99%, and exercise time during each bout was ≥ 2 hours in 93%. On the other hand, approximately half of respondents who presently exercised did so at a frequency of 1 to 2 days per week. In addition, to eliminate variations due to different interviewers, the survey on habitual exercise was conducted using an interview format by a single investigator. In our study, the training group had less obesity, higher HDL-C, and lower LDL-C than the detraining group. Thus, it is clear that continuing exercise even once per week is important in preventing lifestyle diseases, and discontinuing exercise is just like having never exercised. Since the present study specifically focused on the effect of long-term detraining on MetS, whether beneficial effects of exercise are observed in subjects who had not exercised during their student days but started exercise thereafter was analyzed separately.

With respect to lifestyle habits, snacking and drinking alcohol did not differ among the three groups, but smoking was more common in the detraining group than in the training group. This suggests that discontinuing exercise may have an adverse impact on other lifestyle habits. Detraining might also cause unhealthy dietary habits leading to obesity. However, our survey was limited to snacking, which may not be enough to demonstrate the dietary causes of detraining-induced obesity. In order to clarify this question, we have already started another study to examine the impact of dietary habits on detraining-induced obesity using different subjects.

The limitations of this study include its cross-sectional design and the fact that test values were compared only during the survey period. Baseline (student days) and interim clinical data were not obtained. Moreover, although the type of habitual exercise during the student days was surveyed in detail, due to the wide variety of exercise types, this variable was excluded from our analysis. Indeed, since exercise type (e.g., aerobic, endurance, resistance) and intensity may have different effects on each parameter, this is an issue for future investigation. Furthermore, although the importance of continuing exercise was demonstrated, frequency was not evaluated. Thus, when conducting a longitudinal study on the influence of detraining on MetS, a study designed to clarify the above points is necessary.

In conclusion, detraining (discontinuing exercise) led to obesity and lower HDL-C, to the same extent as in the non-training group, MetS risk factors were increased, and LDL-C was increased. Therefore, guidance to adults to continue present physical exercise, and guidance to youth not to discontinue physical exercise, must be provided to prevent future lifestyle-related diseases.

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The authors declare no conflicts of interest.

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Relation of body composition to daily physical activity in free-living Japanese adult women

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Abstract

The objective of the present study was to investigate the relationship between the indices of body size such as BMI, fat-free mass index (FFMI, FFM/height^2), fat mass index (FMI, FM/height^2), and body fat percentage (%BF), and physical activities assessed by the doubly-labelled water (DLW) method and an accelerometer in free-living Japanese adult women. We conducted a cross-sectional study in 100 female subjects ranging in age from 31 to 69 years. Subjects were classified in quartiles of BMI, FFMI, FMI and %BF. Daily walking steps and the duration of light to vigorous physical activity were simultaneously assessed by an accelerometer for the same period as the DLW experiment. Only physical activity-related energy expenditure (PAEE)/FFM and PAEE/body weight (BW) decreased in the highest quartile of BMI. Physical activity level, PAEE/FFM and PAEE/BW decreased in the highest quartile of FMI and %BF, whereas they were not different among quartiles of FFMI. Daily walking steps and the duration of moderate- and vigorous-intensity physical activities decreased or tended to decrease in the highest quartile of FMI and %BF, but did not differ among quartiles of FFMI and BMI. These results clearly showed that Japanese adult women with higher fat deposition obviously had a low level of physical activities assessed by both the DLW method and accelerometry, but those with larger BMI had lower PAEE/FFM and PAEE/BW only. Our data suggest that the relationship between obesity and daily physical activities should be discussed using not only BMI but also FMI or %BF.

Key words: **Body composition: Physical activity: Doubly-labelled water: Accelerometry: Japanese adult women**

Obesity is caused by an imbalance between energy intake and energy expenditure. Obese individuals are often considered to be physically less active than normal-weight individuals. However, most cross-sectional studies using the doubly-labelled water (DLW) method, which is known to be the most accurate method of measuring energy expenditure in free-living conditions[1,2], have reported that physical activity level (PAL; the ratio of total energy expenditure(TEE):BMR) did not differ among BMI categories[3–6]. The reason for the lack of this association may be partly explained by differences in the distribution of fat-free mass (FFM) and fat mass (FM). PAL appears to be negatively associated with FM[7,8], but not correlated with FFM[5]. However, these studies have only reported information on the association between PAL and either FM or FFM, which are not adjusted for body size, such as body height. To our knowledge, no information is available from thoroughly examining the relationship between BMI or body composition, i.e. FFM index (FFMI, FFM divided by height squared), FM index (FMI, FM divided by height squared) or body fat percentage (%BF) and physical activity in adult women, particularly in Asian populations.

Recently, many cross-sectional studies on adult women in Western countries and Japan reported that BMI and %BF were inversely associated with daily walking steps[9,10]. Furthermore, %BF was negatively associated with the duration of vigorous-intensity physical activity assessed by accelerometry[11]. Therefore, not only physical activity-related energy expenditure (PAEE) but also the intensity of the physical activity or walking steps should be lower among adult women with higher body mass or fat deposition.

In the present study, we investigated the relationship between various indices of body size such as BMI, FFMI,

Abbreviations: %BF, body fat percentage; BW, body weight; DHQ, diet history questionnaire; DMW, doubly-labelled water; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; METs, metabolic equivalents; PAEE, physical activity-related energy expenditure; PAL, physical activity level; SCOP, Saku Control Obesity Program; TEE, total energy expenditure.

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FMI and %BF, and daily physical activities assessed by the DLW method and accelerometry in free-living Japanese adult women.

Methods

Subjects

Study participants were recruited through healthcare centres or at workplaces from various prefectures of the Kanto area (central Japan) and the Kyushu area (Western Japan), and from the Saku Control Obesity Program (SCOP). The details of SCOP are described elsewhere(12). In each location, subjects were included according to the following criteria: (a) in good health; (b) not pregnant or breast-feeding; (c) BMI higher than 18·5 kg/m^2; (d) living in their home prefecture 2 weeks before and during the study; (e) not on a weight-loss or treatment diet; and (f) alcohol consumption less than 40 g/d. As a result, 100 female subjects aged 31 to 69 years participated in the present study. Daily physical activity was estimated over the 14 d study period in free-living conditions using the DLW method and accelerometry. Over the entire assessment period, subjects were carefully instructed to maintain their normal daily activities and eating patterns and to make no conscious effort to lose or gain weight.

Procedures

The experimental design is shown in Fig. 1. Participants completed two visits to study sites on day 0 and day 15. On the day before the start of measuring physical activity (day 0), urine samples were collected early in the morning, 12 h or longer after the last meal (baseline urine sample), and body weight (BW) and height were measured. BMR was measured in the supine position and then the participants received a dose of DLW. On the day after the physical activity measurement (day 15), BW was measured and we then received back the urine samples, accelerometer and a self-administered diet history questionnaire (DHQ). The present study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan. All subjects gave their written informed consent before the commencement of the investigations.

Anthropometric measures

Anthropometric measures were obtained in the fasting state on the day before (day 0) and after the 14 d study period (day 15). BW was measured to the nearest 0·1 kg and height to the nearest 0·1 cm, in individuals wearing the lightest clothing, with underwear and no shoes. BMI was calculated as BW (kg) divided by the square of body height (m^2).

Diet history questionnaire

The DHQ is a validated sixteen-page structured questionnaire that assesses dietary habits in the preceding 1-month period(13). Well-trained dietitians checked the DHQ to find omissions or errors and corrected them by asking questions of each participant. Details of the DHQ, methods of calculating nutrients and validity are given elsewhere(13). We calculated the food quotient using the data from the DHQ to evaluate TEE.

Doubly-labelled water

After providing a baseline urine sample, a single dose of approximately 0·06 g ^2H_2O/kg BW (99·8 atom%; Cambridge Isotope Laboratories, Andover, MA, USA) and 1·4 g $H_2{}^{18}O$/kg BW (10·0 atom%; Taiyo Nippon Sanso, Tokyo, Japan) was given orally to each subject on day 0. After dose administration, participants were asked to collect urine samples on day 1 (the day after the DLW dose) and on eight additional times during the study period at the same time of the day (Fig. 1). All urine samples except for the baseline one were collected by the participant either at home or their place of work, and the time of sampling was recorded. All samples were first stored by freezing at −30°C in airtight parafilm-wrapped containers, and then analysed in our laboratory.

Gas analysis

Gas samples for the isotope ratio mass spectrometer were prepared by equilibration of urine samples with a gas. The gas for equilibration of ^{18}O was CO_2 and that for ^2H was H_2. Pt catalyst was used for equilibration of ^2H. The urine was analysed by a DELTA Plus isotope ratio mass spectrometer (Thermo Electron Corporation, Bremen, Germany). Each sample and the corresponding reference were analysed in duplicate.

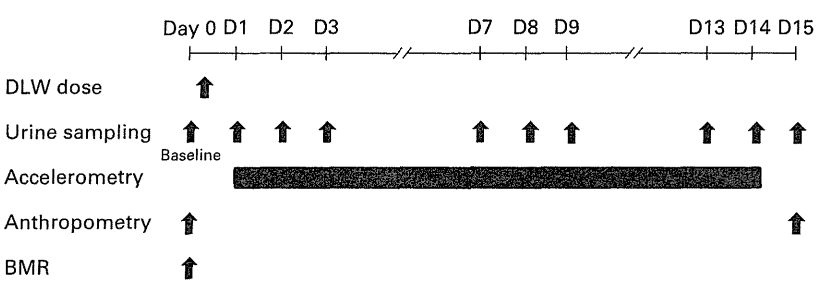

Fig. 1. Schematic representation of the experimental design. On day 0, the $^2H_2{}^{18}O$ (doubly-labelled water; DLW) dose was given orally to each subject after collecting a baseline urine sample and performing the BMR and anthropometric measurements.

The average standard deviations through the analyses were 0·5‰ for ^2H and 0·03‰ for ^{18}O.

Calculations of total energy expenditure and body composition

The ^2H and ^{18}O zero-time intercepts and elimination rates (k_H and k_O) were calculated by using a least-squares linear regression on the natural logarithm of the isotope concentration as a function of the elapsed time from dose administration. The zero-time intercepts were used to determine the isotope pool sizes. Total body water (TBW) was calculated from the mean value of the isotope pool size of ^2H divided by 1·041 and that of ^{18}O divided by 1·007. FFM was calculated assuming a FFM hydration of 0·732[14]. FM was calculated as BW minus FFM and %BF was then computed from BW and FFM. The TEE (kJ/d) calculation was performed using a modification of Weir's formula[15] based on the CO_2 production rate (rCO_2) and respiratory quotient. rCO_2 was calculated as follows: $rCO_2 = 0{\cdot}4554 \times TBW \times (1{\cdot}007k_O - 1{\cdot}041k_H)$. The food quotient calculated from DHQ was used instead of the respiratory quotient. This assumes that under conditions of perfect nutrient balance the food quotient must equal the respiratory quotient[16,17]. PAL was estimated by dividing TEE by BMR. PAEE was calculated as $0{\cdot}9 \times TEE - BMR$, assuming the thermic effect of food was 10 % of TEE[18].

BMR

BMR was measured in the supine position in the early morning 12 h or longer after the last meal, as described previously[19]. The measurement was performed using a Douglas bag for 10 min × 2 with 1 min of intermission. After the expired air was sampled, the O_2 and CO_2 concentrations were measured using a gas analyser (Arco System, AR-1, Kashiwa, Japan for the participants from the SCOP study, or Arco System, ARCO-1000, Kashiwa, Japan, for the rest of the participants) and the volume of expired air was measured with a certified dry gas meter (DC-5; Shinagawa, Tokyo, Japan). BMR was estimated from O_2 consumption and CO_2 production using Weir's equation[15].

Accelerometry

The Lifecorder EX (Suzuken Co., Ltd, Nagoya, Japan) is a uniaxial accelerometer widely used in many countries due to its reasonable cost and reliable validity for measuring metabolic equivalents (METs) and step counts[20–22]. In the present study, the Lifecorder EX was attached on the left side of the waist at the midline of the left thigh. The movement data are categorised into eleven activity levels (0, 0·5, and 1 to 9). We applied METs for each activity level according to the study of Kumahara *et al.*, and the intensity of activity was divided into light (<3 METs), moderate (≥3 and < 6 METs) and vigorous (≥6 METs)[20].

Statistics

All values are presented as mean values and standard deviations. BMI was calculated as BW (measured before DLW dose) divided by height squared. FFMI and FMI were calculated as FFM and FM divided by height squared, respectively. Subjects were classified by quartiles of BMI, FFMI, FMI and %BF. Homoscedasticity or homogeneity of variances was examined using Levene's test. Because some variables in physical characteristics did not follow a normal distribution, the non-parametric test of Kruskal–Wallis analysis was used to compare the variables in physical characteristics among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons. In variables that were normally distributed, one-way ANOVA was used to compare the variables among quartiles and Fisher's least square difference was used as a *post hoc* test for multiple comparisons. The associations between physical activities and body size or composition were examined by linear regression analysis. In one-way ANOVA, *post hoc* tests and Kruskal–Wallis tests, differences were considered to be statistically significant if the *P* value was less than 0·05; using the Mann–Whitney *U* test, differences were deemed significant at $P < 0{\cdot}0125$ (modification using Bonferroni's inequality). All statistical treatments were done using SPSS for Windows (version 16.0J; SPSS Inc., Chicago, IL, USA).

Results

Of the total 100 women studied, the proportion of normal-weight (BMI ≥ 18·5 to < 25 kg/m^2) and overweight participants (BMI ≥ 25 kg/m^2) was 76 and 24 %, respectively. The mean age of the subjects was 51·8 (SD 11·2; range 31–69) years. The mean BW and BMI were 57·4 (SD 12·2; range 41·7–109·7) kg and 23·5 (SD 4·4; range 18·8–40·0) kg/m^2, respectively. BW did not change during the study (change of BW 0·02 (SD 0·7) kg; P=0·987). The range of PAL was 1·36–2·52, with a mean value of 1·88.

Physical characteristics and physical activity variables among quartiles of BMI, FFMI, FMI and %BF are shown in Tables 1–4, respectively. Among the physical characteristics, age and height were not significantly different among quartiles. BMI increased linearly with FMI (r 0·943) and %BF (r 0·749), whereas FFM increased in the 4th quartiles of FMI and %BF (Tables 3 and 4).

Of energy expenditure components, TEE/BW decreased linearly with BMI, FMI and %BF. On the other hand, TEE/BW decreased only in the 4th quartile of FFMI (Table 2). PAEE/FFM and PAEE/BW decreased in the 4th quartile of BMI, but PAL did not differ among quartiles (Table 1). Among FFMI quartiles, there were no significant differences among PAL, PAEE/FFM and PAEE/BW. However, among FMI quartiles, all PAL, PAEE/FFM and PAEE/BW decreased in the 4th quartile. Among %BF quartiles, PAL and PAEE/FFM were significantly lower in the 3rd and 4th quartiles than in the 2nd quartile, whereas PAEE/BW decreased from the 3rd quartile. Fig. 2 shows that PAL was negatively associated with FMI, but not with BMI and FFMI (Fig. 2). PAEE/FFM and PAEE/BW were

Table 1. Participant characteristics, energy expenditure components and physical activity variables by BMI grouping
(Mean values and standard deviations)

BMI (kg/m²) quartiles‖...	1st (18·6–20·4)		2nd (20·5–22·1)		3rd (22·3–24·7)		4th (24·7–40·0)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	49·7	11·9	51·4	11·8	53·9	11·9	52·4	9·4	0·630	0·038
Height (m)	1·55	0·04	1·56	0·06	1·56	0·04	1·56	0·06	0·890	0·133
Weight (kg)¶	47·1	3·1	52·1††	4·2	57·2††‡‡	3·3	73·0††‡‡§§	13·4	<0·001	0·948***
BMI (kg/m²)¶	19·5	0·6	21·3††	0·5	23·5††‡‡	0·9	29·8††‡‡§§	3·9	<0·001	1
%BF¶	28·9	5·1	32·3	4·3	36·0††‡‡	5·0	42·0††‡‡§§	4·6	<0·001	0·747***
FFM (kg)¶	33·5	2·5	35·7	3·6	36·3††	3·8	42·2††‡‡§§	6·7	<0·001	0·743***
FM (kg)¶	13·7	2·8	16·9††	2·7	20·6††‡‡	3·3	30·5††‡‡§§	7·7	<0·001	0·930***
Energy expenditure										
TEE (kJ/d)	8441	1149	8534	883	9333†‡	1244	9939††‡‡	1523	<0·001	0·527***
TEE/BW (kJ/d per kg)	179·8	27·1	164·7†	21·2	163·5†	23·0	138·1††‡§§	20·4	<0·001	−0·588***
BMR (kJ/d)	4492	351	4604	462	4777	588	5558††‡‡§§	892	<0·001	0·725***
PAL	1·88	0·23	1·85	0·22	1·97	0·27	1·80	0·18	0·065	−0·187
PAEE (kJ/d)	3105	913	3077	747	3623	1069	3387	886	0·099	0·120
PAEE/FFM (kJ/d per kg)	92·4	24·8	86·8	21·8	100·7‡	30·6	81·3§	20·3	0·040	−0·207*
PAEE/BW (kJ/d per kg)	66·2	20·6	59·7	16·0	63·8	19·7	47·5††‡§§	13·1	0·001	−0·403***
Accelerometer										
Step counts (per d)	8994	2151	8872	2619	8624	2729	7808	3402	0·427	−0·286**
Light (<3 METs) (min/d)	57·0	15·8	58·4	23·0	62·0	24·8	55·0	20·3	0·691	−0·107
Moderate (≥ 3 and < 6 METs) (min/d)	28·8	12·0	27·1	13·8	23·3	10·2	21·0	13·8	0·122	−0·316**
Vigorous (≥ 6 METs) (min/d)	3·7	3·4	3·0	2·9	2·7	2·7	2·0	2·7	0·246	−0·239*

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.
* Significant correlation with BMI: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.
Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.
Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.
Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.
‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.
¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 2. Participant characteristics, energy expenditure components and physical activity variables by fat-free mass index (FFMI) grouping
(Mean values and standard deviations)

FFMI quartiles‖...	1st (12·2–13·8)		2nd (13·8–14·6)		3rd (14·7–15·6)		4th (15·7–21·6)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	48·5	12·9	55·6	10·5	54·0	10·9	49·1	9·1	0·054	−0·026
Height (m)	1·56	0·05	1·56	0·05	1·55	0·06	1·57	0·05	0·587	0·093
Weight (kg)¶	50·1	4·4	52·0	4·5	56·2††	7·7	71·1††‡‡§§	15·1	<0·001	0·753***
BMI (kg/m^2)¶	20·6	1·4	21·6	2·1	23·3††	2·6	28·7††‡‡§§	5·2	<0·001	0·794***
%BF¶	34·9	4·0	32·8	6·2	33·9	7·4	37·6	8·3	0·045	0·247*
FFM (kg)¶	32·2	2·0	34·6††	2·2	36·8††‡‡	2·8	44·0††‡‡§§	4·9	<0·001	0·890***
FM (kg)¶	17·6	3·2	17·2	4·5	19·5	6·4	27·3††‡‡§§	10·5	<0·001	0·581***
FFMI (kg/m^2)	13·3	0·4	14·3	0·3	15·2	0·3	17·8	1·5	<0·001	1
Energy expenditure										
TEE (kJ/d)	8017	891	8676	932	9306††	1100	10 248††‡‡§§	1358	<0·001	0·626***
TEE/BW (kJ/d per kg)	160·9	20·2	167·6	20·2	169·3	35·2	148·4‡§	26·8	0·025	−0·262**
BMR (kJ/d)	4391	444	4582	423	4871††‡	533	5587††‡‡§§	826	<0·001	0·708***
PAL	1·83	0·18	1·91	0·24	1·92	0·29	1·85	0·20	0·484	−0·064
PAEE (kJ/d)	2824	659	3226	841	3505†	1090	3636††	890	0·011	0·263**
PAEE/FFM (kJ/d per kg)	88·0	21·9	93·4	24·5	96·3	31·0	83·6	22·6	0·368	−0·151
PAEE/BW (kJ/d per kg)	56·6	13·1	62·4	17·1	64·5	24·7	53·6	17·3	0·182	−0·157
Accelerometer										
Step counts (per d)	8589	2592	8914	2437	8267	2635	8528	3403	0·878	−0·159
Light (<3 METs) (min/d)	53·6	20·4	59·1	17·2	55·7	18·9	64·1	26·5	0·320	0·040
Moderate (≥ 3 and < 6 METs) (min/d)	28·0	15·2	27·3	10·4	23·9	12·0	21·1	12·3	0·187	−0·300**
Vigorous (≥ 6 METs) (min/d)	3·4	3·0	2·6	2·8	3·1	3·6	2·3	2·3	0·513	−0·108

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.

* Significant correlation with FFMI: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.

Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.

Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.

‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.

¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 3. Participant characteristics, energy expenditure components and physical activity variables by fat mass index (FMI) grouping

(Mean values and standard deviations)

FMI quartiles‖...	1st (2·94–6·39)		2nd (6·49–7·52)		3rd (7·55–9·73)		4th (9·82–19·49)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	49·9	10·9	52·4	12·2	51·4	11·6	53·5	10·3	0·713	0·085
Height (m)	1·56	0·05	1·56	0·05	1·56	0·05	1·56	0·06	0·921	0·138
Weight (kg)¶	48·3	4·5	51·7	4·5	56·7††‡‡	4·4	72·8††‡‡§§	13·5	<0·001	0·897***
BMI (kg/m^2)¶	19·9	1·2	21·3††	1·2	23·2††‡‡	1·7	29·6††‡‡§§	4·2	<0·001	0·943***
%BF¶	26·4	4·2	32·9††	1·5	37·1††‡‡	1·7	42·9††‡‡§§	3·9	<0·001	0·916***
FFM (kg)¶	35·6	3·9	34·9	4·0	35·7	3·3	41·5††‡‡§§	7·1	0·001	0·565***
FM (kg)¶	12·8	2·4	17·0††	1·3	21·0††‡‡	1·7	30·9††‡‡§§	7·2	<0·001	0·982***
FMI (range) (kg/m^2)	5·3	0·9	7·0	0·3	8·6	0·7	12·6	2·3	<0·001	1
Energy expenditure										
TEE (kJ/d)	8810	1097	8782	1258	9049	1346	9607	1576	0·110	0·352***
TEE/BW (kJ/d per kg)	183·4	25·4	170·0†	20·7	159·4††	17·2	133·3††‡‡§§	16·7	<0·001	−0·696***
BMR (kJ/d)	4586	375	4584	457	4760	559	5503††‡‡§§	971	<0·001	0·610***
PAL	1·91	0·22	1·93	0·28	1·91	0·21	1·76†‡§	0·19	0·036	−0·254*
PAEE (kJ/d)	3343	847	3320	1082	3384	914	3143	876	0·827	−0·017
PAEE/FFM (kJ/d per kg)	94·3	23·6	95·9	31·3	94·3	21·1	76·8†‡‡§	20·4	0·024	−0·258**
PAEE/BW (kJ/d per kg)	69·6	19·0	64·2	19·5	59·4†	14·0	43·9††‡‡§§	11·7	<0·001	−0·502***
Accelerometer										
Step counts (per d)	8508	2034	9724	2154	8866	3387	7200‡‡§	2777	0·011	−0·293**
Light (<3 METs) (min/d)	56·5	17·0	63·0	21·2	61·3	26·5	51·7	17·8	0·224	−0·156
Moderate (≥ 3 and < 6 METs) (min/d)	24·9	9·7	30·3	13·2	25·7	14·6	19·3‡‡	11·0	0·021	−0·265**
Vigorous (≥ 6 METs) (min/d)	3·8	3·5	3·5	3·0	2·3	2·1	1·8†‡	2·7	0·042	−0·282**

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.

* Significant correlation with FMI: * *P*<0·05, ** *P*<0·01, *** *P*<0·001.

Mean value was significantly different from that for the 1st quartile: † *P*<0·05, †† *P*<0·01.

Mean value was significantly different from that for the 2nd quartile: ‡ *P*<0·05, ‡‡ *P*<0·01.

Mean value was significantly different from that for the 3rd quartile: § *P*<0·05, §§ *P*<0·01.

‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.

¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 4. Participant characteristics, energy expenditure components and physical activity variables by body fat percentage (%BF) grouping
(Mean values and standard deviations)

%BF quartiles‖...	1st (15·9–31·0)		2nd (31·4–34·5)		3rd (34·6–38·8)		4th (39·1–54·3)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	48·7	10·6	53·8	12·3	50·3	11·3	53·8	10·2	0·596	0·138
Height (m)	1·56	0·06	1·55	0·04	1·56	0·05	1·57	0·06	0·839	0·112
Weight (kg)¶	49·0	5·4	53·4†	6·5	54·8††	4·3	72·3††‡‡§§	13·9	< 0·001	0·710***
BMI (kg/m^2)¶	20·1	1·3	22·1††	2·2	22·6††	2·0	29·3††‡‡§§	4·5	< 0·001	0·749***
%BF¶	26·2	4·1	32·7††	0·9	37·0††‡‡	1·2	43·2††‡‡§§	3·4	< 0·001	1
FFM (kg)¶	36·1	4·2	36·0	4·5	34·5	2·6	41·0‡§§	7·2	0·005	0·278**
FM (kg)¶	12·9	2·7	17·5††	2·4	20·3††‡‡	1·8	30·9††‡‡§§	7·2	< 0·001	0·889***
Energy expenditure										
TEE (kJ/d)	8845	1091	9326	1375	8600	1090	9477	1657	0·074	0·122
TEE/BW (kJ/d per kg)	182·1	26·9	175·0	19·4	156·6††‡‡	13·1	132·4††‡‡§§	15·5	< 0·001	− 0·725***
BMR (kJ/d)	4640	372	4727	530	4680	556	5385††‡‡§§	1041	< 0·001	0·368***
PAL	1·90	0·22	1·98	0·26	1·85‡	0·22	1·78‡‡	0·19	0·013	− 0·243*
PAEE (kJ/d)	3321	861	3666	1072	3059	806	3144	872	0·099	− 0·124
PAEE/FFM (kJ/d per kg)	92·5	24·5	102·6	29·6	88·2‡	20·6	77·9‡‡	20·6	0·006	− 0·244*
PAEE/BW (kJ/d per kg)	68·5	19·8	68·7	18·1	55·5††‡‡	12·8	44·4††‡‡§	12·0	< 0·001	− 0·515***
Accelerometer										
Step counts (per d)	8675	2082	9449	2173	9067	3288	7107†‡‡§	2869	0·013	− 0·293**
Light (< 3 METs) (min/d)	58·0	16·2	64·9	23·1	59·2	24·6	50·4	18·1	0·113	− 0·168*
Moderate (≥ 3 and < 6 METs) (min/d)	25·7	10·2	26·4	11·2	28·7	15·7	19·4	11·8	0·057	− 0·154
Vigorous (≥ 6 METs) (min/d)	3·4	3·4	3·9	3·0	2·3	2·3	1·8	2·7	0·052	− 0·287**

FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.
* Significant correlation with %BF: * *P*<0·05, ** *P*<0·01, *** *P*<0·001.
Mean value was significantly different from that for the 1st quartile: † *P*<0·05, †† *P*<0·01.
Mean value was significantly different from that for the 2nd quartile: ‡ *P*<0·05, ‡‡ *P*<0·01.
Mean value was significantly different from that for the 3rd quartile: § *P*<0·05, §§ *P*<0·01.
‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.
¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

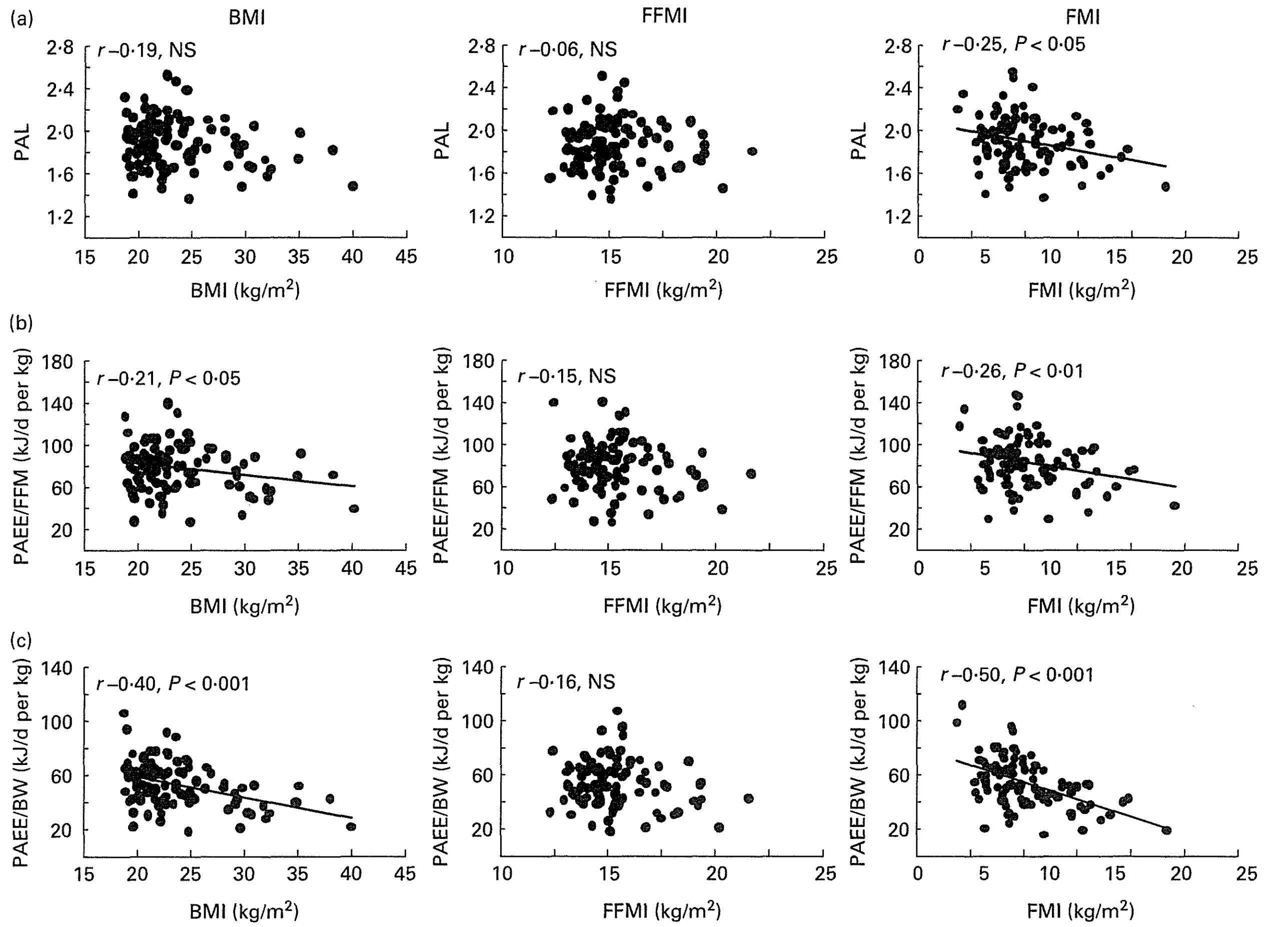

Fig. 2. Relationships between BMI, fat-free mass index (FFMI) or fat mass index (FMI) and physical activity level (PAL) (a), physical activity-related energy expenditure/fat-free mass (PAEE/FFM) (b) or PAEE/body weight (BW) (c). PAL = TEE/BMR, where TEE is total energy expenditure; PAEE = 0·9TEE − BMR; FMI was negatively associated with all physical activity variables obtained by the doubly-labelled water method.

negatively associated with BMI and FMI, but not with FFMI (Fig. 2).

In the accelerometry data, the step counts decreased in the 4th quartile of FMI (Table 3) and %BF (Table 4), whereas there was no difference among quartiles of BMI (Table 1) and FFMI (Table 2). Time spent on moderate- or vigorous-intensity activity decreased in the 4th quartile of FMI, whereas it did not differ among quartiles of BMI, FFMI and %BF. Time spent on light-intensity activity did not differ among quartiles of BMI, FFMI, FMI and %BF.

Discussion

The principal finding in the present study was that only PAEE/FFM and PAEE/BW assessed by the DLW method decreased among women in the highest quartile of BMI. On the other hand, women in the highest quartiles of FMI and %BF obviously had a low level of physical activities assessed by both the DLW method and accelerometer. Particularly, women in the 3rd quartile of FMI or %BF had lower PAEE/BW even though their BMI was below 25 kg/m^2.

The average PAL of 1·88 in the participants of the present study was a little higher than that of 1·75 in the general population of Eastern or Western countries[7,16,23,24]. The average BMR in the present data was 88·3 kJ/d per kg BW for normal-weight women (BMI < 25 kg/m^2) and 76·2 kJ/d per kg BW for overweight women (BMI ≥ 25 kg/m^2). These values were close to the average BMR of 88·8 kJ/d per kg BW for Japanese normal-weight adult women[25] and 74·9 kJ/d per kg BW in Japanese overweight adult women[19]. Moreover, the range of PAL in the present study was 1·36–2·52, which is within the PAL of the general population[26]. The average daily steps of about 8500 for participants in the present study were also comparatively higher than the daily steps for Japanese adults women, who generally walk an average of 7215 steps/d[27].

The lack of a significant difference in PAL among BMI quartiles in the present study is consistent with most previous studies[4–6]. In contrast, Tooze *et al.*[28] demonstrated that PAL was lower in obese women (BMI ≥ 30 kg/m^2) than in normal-weight women (BMI < 25 kg/m^2). However, they used an estimated RMR, but not a measured rate, so some errors in estimating PAL may be induced by the

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Table 5. Concordance of classification between BMI and fat mass index (FMI) or percentage body fat (%BF)
(Percentages and number of subjects)

	FMI								%BF							
Quartile*...	1st		2nd		3rd		4th		1st		2nd		3rd		4th	
BMI quartile	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
1st (lowest)	68	17	32	8	0	0	0	0	60	15	28	7	12	3	0	0
2nd	28	7	44	11	28	7	0	0	36	9	32	8	32	8	0	0
3rd	4	1	24	6	56	14	16	4	4	1	32	8	40	10	24	6
4th (highest)	0	0	0	0	16	4	84	21	0	0	8	2	16	4	76	19

* There are twenty-five subjects in each quartile.

different accuracy of estimated RMR between lean and obese participants[19].

Only PAEE/FFM and PAEE/BW decreased among women in the highest quartiles of BMI, whereas not only PAEE/FFM and PAEE/BW but also PAL apparently decreased in the highest quartile of FMI and %BF. Based on the results of the concordance of classification between BMI and FMI or %BF, most participants with a higher BMI have higher FM as well (Table 5). Thus, women in the highest quartile of BMI might be less active on the basis of PAEE when adjusting for body size. Contrary to the results of the present study, Snodgrass *et al.*[29] reported that PAEE/BW was not different between lean and overweight women. However, lean and normal-weight women in their study had much lower PAL (1·43 (SD 0·21)) and two of the seven women were underweight (BMI < 18·5 kg/m^2).

In contrast to the results of the decrease in PAEE/FFM and PAEE/BW among women in the highest quartile of BMI, there were no differences in PAEE/FFM and PAEE/BW among normal-weight women in the 1st to 3rd quartiles of BMI. Among participants in the 3rd quartile of BMI, the proportion of participants who are included in the 3rd quartile of FMI was only about half and the remaining spread to the other quartiles of FMI (Table 5). This phenomenon was similar to that of participants in the 2nd quartile of BMI. Thus, there appears to be a considerably large interindividual variability, especially for PAEE/FFM in normal-weight women who have a different distribution of FFM and FM at the same BMI.

The present study showed that TEE/BW was correlated with BMI, FMI or % BF. However, the overcorrection of TEE when adjusted by BW should be cautiously interpreted, because BMR accounts for approximately 60 % of TEE in an individual with a PAL of 1·75. On the other hand, in PAEE, which is not influenced by BMR, someone with a larger body mass needs more energy for an activity than someone with a smaller body mass. Thus, PAEE/BW may well reflect lower physical activity among women in the highest quartile of BMI. However, we could not exclude the possibility that PAEE/BW might be also adjusted excessively because there was a great difference in BW and FM between the 3rd and 4th quartile of BMI in the present study. However, among quartiles of FMI and %BF, PAEE/BW was lower in the 3rd quartile than in the 1st or 2nd quartile, although it was not a great difference in BW between the 3rd quartile and the 1st or 2nd quartile. Therefore, lower PAEE/BW could well reflect the status of lower physical activity in women with higher BMI, especially with higher fat deposition, when FMI or %BF was effectively used.

Schulz *et al.*[7] reported a high correlation between PAEE/BW and %BF in healthy adult women, thereby providing support for our data that PAEE/BW decreased from the 3rd quartiles of FMI and %BF. Thus, PAEE/BW could be useful to understand daily physical activity, especially in normal-weight women with higher fat deposition.

Step counts and the duration of physical activity of moderate or vigorous intensity assessed by accelerometry apparently decreased in the highest quartile of FMI, but not among quartiles of BMI and FFMI. Contrary to the present results of no difference in step counts and moderate or vigorous intensity among BMI quartiles, Levine *et al.*[30] reported that the allocation of standing and ambulating during the day was lower in obese subjects than in lean subjects when using BMI cut-points. This discrepancy may be due to the different range of PAL among populations. Levine *et al.*[30] recruited both lean and obese individuals from among 'couch potato' subjects, all of whom were sedentary. The populations of the present study were free-living Japanese adult women with a wide PAL range from sedentary to active.

In a longitudinal study using the DLW method in adult women, Schoeller *et al.*[31] demonstrated that increases in weight were lower in active women with a PAL above 1·75. The present study did not attempt to determine a threshold of daily physical activity that is required to have a normal FMI, %BF or BMI due to the limited number of study subjects and the proportion of obese individuals in the present dataset. Another reason was that there were no definite cut-offs for FMI and %BF. Because the present study apparently showed a good relationship between FM (FMI or %BF) and various physical activities, further study is warranted to examine the threshold of daily physical activity that is required to suppress fat accumulation.

The BMI cut-off point is used as the standard for a classification of obesity. On the other hand, Bigaard *et al.* suggested that FMI was also an independent predictor of all-cause mortality in their epidemiological study[32]. They revealed that an excess of approximately 10 kg/m^2 of FMI value was associated with considerably increased mortality. The present study showed that Japanese adult women with an average FMI of 12·6 kg/m^2 were less active than those with a below-average FMI of 8·6 kg/m^2. Therefore, we consider that an increase in

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PAL may decrease FMI, leading to a decrease in risk of all-cause mortality.

The present study has the following limitations: first, the FFM hydration was assumed as 0·732 for all participants equally[14], so some errors in estimating FFM may be induced by the different levels of obesity. Second, the present results were drawn from a cross-sectional design. Therefore, we were not able to infer a cause–effect relationship between an inactive lifestyle and obesity. Observational or intervention studies with longitudinal design are needed to evaluate the effect of inactivity on the development of obesity for adult women. However, the main purpose of the present study was to investigate the relationship between daily physical activity and body size or body composition. Moreover, the present study provided the results only for Japanese adult women, but not for men or children.

In conclusion, Japanese adult women with larger BMI had lower PAEE adjusted by FFM or BW. Especially, Japanese adult women with higher fat deposition were apparently less active, on the basis of not only PAEE but also the physical activity of moderate or vigorous intensity. The present data suggest that the relationship between obesity and daily physical activities should be discussed using not only BMI but also FMI or %BF.

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原著

生体電気インピーダンス法による皮下脂肪厚の推定

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索引用語：皮下脂肪厚，生体電気インピーダンス法，超音波法，推定

本研究では，生体電気インピーダンス法により皮下脂肪厚を推定する妥当性を検討した．被験者は23～68歳の健常な男女71名であり，彼らは無作為にグループⅠとグループⅡの２群へと分類された．Bモード超音波法により上腕前・後部，大腿前部および腹部における皮下脂肪厚を測定し，本研究の基準値として採用した．局所インピーダンス計測器を用いて，超音波法と同位置におけるレジスタンス(R)およびリアクタンス(X)を測定した．グループⅠを対象に，算出したR／Xと皮下脂肪厚の基準値との関係式を用いて皮下脂肪厚の推定式を作成した．その結果，グループⅠにおいて，皮下脂肪厚の基準値と推定値との間における回帰式はY＝Xとの間に有意差がなかった．一方，皮下脂肪厚の蓄積が顕著である個人ほど過大評価されたものの，皮下脂肪厚が43 mm以上となる箇所を除くと系統誤差の有意性が消失し，この場合における推定値の標準誤差(SEE)は3.3 mmであった．同じ推定式をグループⅡに適用した場合においても結果は同様であり，皮下脂肪厚が43 mm以上となる2箇所を除外した場合におけるSEEは3.5 mmであった．以上の結果より，本研究の手法を用いて身体局所から測定したR／Xにより，43 mm以下の部位における皮下脂肪厚を簡便に推定可能であることが示唆された．

はじめに

体脂肪の過度な蓄積は健康障害をもたらすと考えられている．近年，特に内臓脂肪の蓄積がメタボリックシンドロームや心臓血管疾患の発症と関連を持つことから，それらの罹患者を簡便にスクリーニングするための手段として，ウエスト周囲長の測定が推奨されている．一方，体脂肪の大半を占める皮下脂肪も，癌による死亡リスク[1)]や末梢動脈疾患の発症[2)]と関連を持つ．また，閉経後の女性における皮下脂肪分布の上半身型への変化は脂質異常症と関連する[3)]．上腕や体幹の皮下脂肪厚とHDLコレステロールとの間に負の相関が認められることも報告されている[4)]．したがって，部位別の皮下脂肪を定量し，その全身における分布の違いを観察することは，内臓脂肪の蓄積におけるウエスト周囲長の観察と同様に，予防医学の観点から有用と思われる[5)]．しかしながら，現在までのところ，皮下脂肪量を簡便かつ正確に定量する手段は確立されていない．皮下脂肪を定量する上で最も正確とされている核磁気共鳴画像法[6,7)]は，機材が高

Predicting Subcutaneous Fat Thickness by Bioelectrical Impedance Analysis
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価である上実験室外での測定が不可能であり，大多数の被験者に対して適用することができない．そのため，実験室外での調査を行う場合に皮下脂肪量の基準値として利用されるのは，超音波法により測定した皮下脂肪厚である(e.g. Ishida et al. 1995)[8]．超音波法は，機材の運搬が可能であり，核磁気共鳴画像法に比べれば安価で入手できるものの，個人単位で購入できる価格ではない上，測定に際し専門的な技術習得を必要とするために，誰もが利用できる手段ではない．一方，身体組成を簡便に測定する手段として，実験室内外での大多数の被験者を対象とした調査・研究に利用可能であり，安価で機器を入手できる，生体電気インピーダンス(BI)法が注目されている．BI法は，身体に微弱な高周波電流を印加し，測定した電極間の抵抗(インピーダンス)値より身体組成を推定する方法である．近年，インピーダンスの合成成分であるレジスタンス(R)やリアクタンス(X)が脂肪量と関連を持つことを示唆する報告がいくつかなされている[9~11]ものの，現在までのところ，皮下脂肪のみを推定対象とし，その妥当性を検証した研究はない．また，皮下脂肪量の蓄積にみられる部位差は体格指数やウエストヒップ比と関連を持たない[6]ことから，皮下脂肪量の測定法には，それ単体で皮下脂肪分布を反映する検出能が必要となるが，そのような検討もなされていない．そこで本研究では，RおよびXを用いて身体各所における皮下脂肪厚の推定を行い，その妥当性について検討することを目的とした．

対象と方法

1．被験者

本研究は，厚生労働科学研究費補助金の助成，ならびに独立行政法人国立健康・栄養研究所における研究倫理審査委員会の承認を受けた「生活習慣病一次予防に必要な身体活動量・体力基準値策定を目的とした大規模介入研究」(Clinical Trials. gov. ID: NCT00926744, Nutrition and Exercise Intervention Study)への参加者のうち，本研究への参加を希望した23～68歳の男女71名を被験者とした．本研究は，株式会社タニタによる「超音波とインピーダンス法による皮下脂肪厚測定について」に対する研究費により実施された．なお，本研究とタニタ社との間には，研究費支給以外の利益関係は存在しなかった．参加者には，本研究の目的や意義，危険性について事前に詳細な説明を行い，研究内容を十分に理解させた上で研究参加への同意を得た．なお，心臓ペースメーカーの装着者や，外科的手術により身体に金属を埋設している者は被験者から除外した．被験者の身体的情報を表1に示した．

2．形態計測

被験者には測定開始12時間前より絶食を指示した．測定時，被験者には立位による解剖学的基本姿勢をとらせ，身長，体重を測定した．さらに，上腕長遠位60％位置における前後部，大腿長遠位50％位置における前部，および臍中心より5 cm右の位置の合計4箇所にマーキングした．なお，本研究における上腕長は肩峰から肘関節の正中線上まで，大腿長は腸骨稜から膝蓋骨上顆まで，下腿長は膝蓋骨上顆から外果までと定義した．

3．超音波法による皮下脂肪厚の測定

本研究では，Bモード超音波法(Aloka社製，SSD-900)により測定した値を皮

表1　被験者の身体的情報(全被験者)

	男性(n=38)				女性(n=33)			
	平均値	標準誤差	最大値	最小値	平均値	標準誤差	最大値	最小値
年齢(歳)	43.4	2.3	67.0	23.0	43.4	2.2	68.0	24.0
身長(cm)	170.2 *	1.0	192.5	160.6	156.6	1.0	166.2	142.0
体重(kg)	71.0 *	1.7	102.6	53.0	55.2	1.5	73.3	39.4
BMI (kg/m^2)	24.5 *	0.5	33.3	19.2	22.5	0.5	29.0	17.7
皮下脂肪厚(mm)								
上腕前部	6.5	0.6	26.9	2.6	8.7	1.0	30.3	3.2
上腕後部	7.7 *	0.7	32.6	4.1	14.1	0.9	37.6	3.7
大腿前部	9.4 *	0.7	37.3	3.2	14.1	1.2	31.1	4.3
腹部	21.3 *	0.7	44.7	8.1	25.4	1.2	58.4	8.2
R / X								
上腕前部	5.8 *	0.7	21.4	2.5	8.0	1.1	29.2	3.1
上腕後部	7.8 *	0.9	29.7	2.8	12.9	1.0	32.7	4.0
大腿前部	9.2 *	1.2	27.1	3.4	12.7	1.6	31.4	4.5
腹部	19.5 *	1.3	28.9	3.6	19.7	2.0	37.6	3.8

* $p < 0.05$