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.

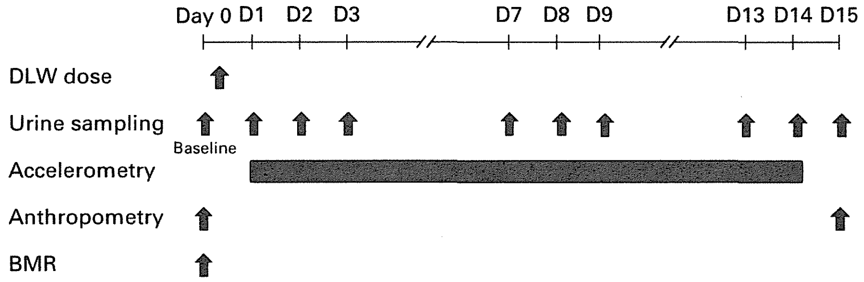

Fig. 1. Schematic representation of the experimental design. On day 0, the $^2H_2{}^{18}O$ (doubly-labelled water; DLW) dose was given orally to each subject after collecting a baseline urine sample and performing the BMR and anthropometric measurements.

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

Calculations of total energy expenditure and body composition

The ^{2}H 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 ^{2}H 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; $P=0{\cdot}987$). 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/m^2) 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/m^2)¶	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.

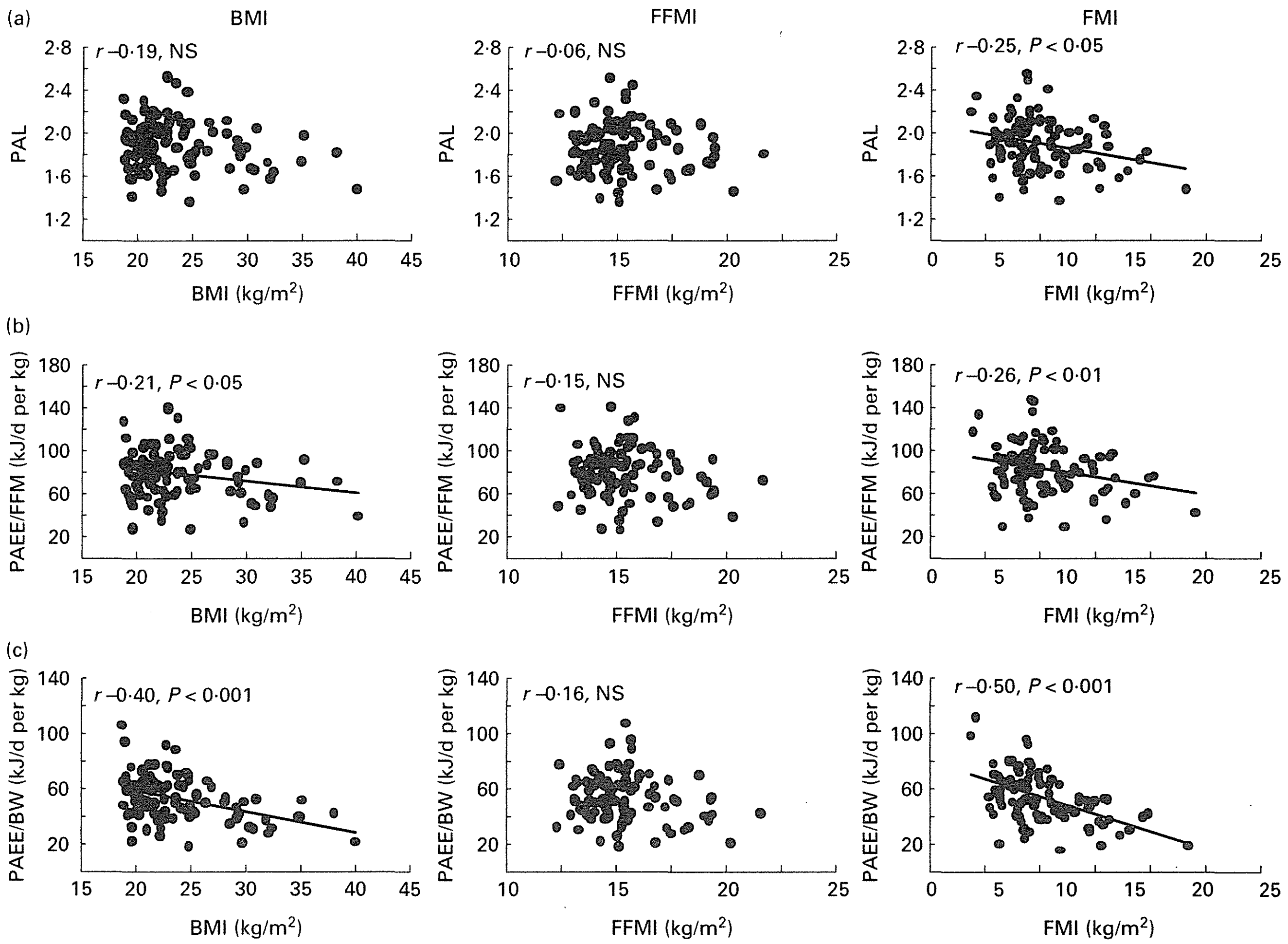

Fig. 2. Relationships between BMI, fat-free mass index (FFMI) or fat mass index (FMI) and physical activity level (PAL) (a), physical activity-related energy expenditure/fat-free mass (PAEE/FFM) (b) or PAEE/body weight (BW) (c). PAL = TEE/BMR, where TEE is total energy expenditure; PAEE = 0·9TEE − BMR; 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 $\geq$ 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 $\geq$ 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

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

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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Validity of Predictive Equations for Basal Metabolic Rate in Japanese Adults

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Summary Many predictive equations for basal metabolic rate (BMR) based on anthropometric measurements, age, and sex have been developed, mainly for healthy Caucasians. However, it has been reported that many of these equations, used widely, overestimate BMR not only for Asians, but also for Caucasians. The present study examined the accuracy of several predictive equations for BMR in Japanese subjects. In 365 healthy Japanese male and female subjects, aged 18 to 79 y, BMR was measured in the post-absorptive state using a mask and Douglas bag. Six predictive equations were examined. Total error was used as an index of the accuracy of each equation's prediction. Predicted BMR values by Dietary Reference Intakes for Japanese (Japan-DRI), Adjusted Dietary Reference Intakes for Japanese (Adjusted-DRI), and Ganpule equations were not significantly different from the measured BMR in either sex. On the other hand, Harris-Benedict, Schofield, and Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University equations were significantly higher than the measured BMR in both sexes. The prediction error by Japan-DRI, Adjusted-DRI, and Harris-Benedict equations was significantly correlated with body weight in both sexes. Total error using the Ganpule equation was low in both males and females (125 and 99 kcal/d, respectively). In addition, total error using the Adjusted-DRI equation was low in females (95 kcal/d). Thus, the Ganpule equation was the most accurate in predicting BMR in our healthy Japanese subjects, because the difference between the predicted and measured BMR was relatively small, and body weight had no effect on the prediction error.

Key Words basal metabolic rate, predictive equation, Japanese, validity

To maintain body weight, energy from food intake must equal energy expenditure. The estimated energy requirement (EER) is defined as the average dietary energy intake that is predicted to maintain energy balance in healthy adults of a given age, gender, weight, height, and level of physical activity consistent with good health (*1*).

Total energy expenditure (TEE) can be divided into basal metabolic rate (BMR), diet-induced thermogenesis, and physical activity (*2*). Calculated from the normal physical activity level (PAL=TEE divided by BMR) of about 1.75 for Japanese (*3*) and Caucasians (*4*), BMR accounts for about 60% of TEE in an adult with normal physical activity in daily life. Therefore, in healthy individuals, EER is usually BMR multiplied by physical activity level, and in unhealthy individuals (patients in clinical settings), EER is BMR multiplied by an activity factor and stress factor (*5*). Thus, it is important to accurately evaluate BMR. However, because of the relatively high cost, limited availability of equipment, the time needed for the measurements, the need for the subject to be in a fasting state, and the need for adequately trained personnel, equations that predict BMR are frequently applied in clinical and field settings instead of indirect calorimetry (*6*).

The international guidelines for nutrition treatment of the American Society for Parenteral and Enteral Nutrition recommend using the Harris-Benedict equation or indirect calorimetric measurement to evaluate BMR (*7*). However, 60% of 515 hospitals in Japan reported the calculation of EERs from body weight (*8*). In addition, only 1.9% of the hospitals carried out indirect calorimetric measurement of BMR. In the clinical setting, the patients' energy expenditure must be estimated accurately because overfeeding or underfeeding

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Table 1. Physical characteristics of subjects.

	All (n=365)	Males (n=163)		Females (n=202)		p values
	Mean±SD	Mean±SD	Range	Mean±SD	Range	
Age (y)	41±17	43±15	20–79	39±18	18–76	0.041
Height (cm)	163.3±9.0	170.3±6.9	146.4–187.7	157.6±5.9	140.8–172.1	<0.001
Weight (kg)	59.5±11.9	67.1±11.2	45.5–110.2	53.3±8.2	36.1–99.1	<0.001
Body mass index (kg/m^2)	22.2±3.1	23.1±3.0	16.8–36.4	21.5±3.0	16.5–36.4	<0.001

Differences between males and females were evaluated by unpaired t-test. p values: males vs. females.

may have adverse effects, such as electrolyte imbalance and gastrointestinal problems (*9*).

BMR is usually calculated from predictive equations using data such as age, sex, height, and weight (*10*). The Harris-Benedict equation (*11*), Schofield equation (*12*), and the Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University (FAO/WHO/UNU) equation (*13*) are internationally used. Harris-Benedict equations were developed from energy expenditure measurements in young Caucasian males and females in 1919 (*11*). Schofield and FAO/WHO/UNU equations were developed using a database of 7,173 subjects (aged from under 3 y to over 60 y) including approximately 45% Italian subjects (*12–15*) and about 50 young Japanese subjects (*16*). Previous studies show that the predictive equations derived mainly from measurements made on Caucasian subjects tend to overestimate BMR in Asians (*9, 10*) as well as in Caucasian subjects (*10, 17–21*). However detailed information on the validity for each sex and age group in Japanese is not available.

In Japan, Dietary Reference Intakes for Japanese (Japan-DRI) provides BMR standards (standard BMR per unit weight) according to sex and age category, and the data for these standards were from a Japanese BMR database (*22, 23*). BMR can be calculated as BMR standards multiplied by body weight. However, the validity of the predictive equations including the predictive equations for BMR standards from the Japan-DRI and the equations for BMR standards to adjust BMR standards for individuals with relatively large or small body weight (*24*) have not been examined in healthy Japanese subjects. In addition, we recently developed new predictive equations for sleeping metabolic rate and BMR in Japanese (*25*).

In the present study, we examined the validity of applying three BMR equations used for Japanese, and three internationally used equations developed mainly from energy expenditure measurements in Caucasian subjects, to healthy Japanese adults.

MATERIALS AND METHODS

Subjects. The data used for the current analysis were collected from different experimental studies that followed a similar methodology. A total of 365 apparently healthy Japanese subjects (163 males and 202 females subjects) were enrolled through personal contact, internet communication, or poster advertisements. The subjects included students, housewives, office workers, and medical colleagues. None had diseases that might affect metabolic rate. The study protocol was explained in advance to the subjects, who were instructed to eat a normal diet and do normal, but not vigorous, physical activity beginning 1 d before measurements. All studies were carried out in the National Institute of Health and Nutrition (Tokyo) and Oita Prefecture. This 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 Tokyo, Japan. All of the subjects signed an informed consent form.

Anthropometric and body composition. Physical characteristics of the subjects are summarized in Table 1. Anthropometric measurements were performed according to the method of Lohman et al. (*26*). Body weight was measured to the nearest 0.1 kg using an electronic scale (YK-150D, YAGAMI, Nagoya, Japan), and body height to the nearest 0.1 cm using a stadiometer (YL-65, YAGAMI). Measurements were performed in light clothing and underwear. The light clothing was weighed and subtracted from the total to obtain body weight with minimal clothing (underwear). Body mass index (BMI: kg/m^2) was calculated as body weight (kg) divided by square of body height (m^2).

Measurements of BMR. Subjects came to the laboratory on the previous night and stayed overnight, or came in the early morning. In the latter case, they were asked to minimize walking prior to their laboratory visit and BMR measurement. Travel time was considered to be within 15 to 90 min in most cases. In most of the previous studies, especially for the Japan-DRI, Schofield, and FAO/WHO/UNU equations, BMR was measured under the latter condition (*23*). BMR was measured in the post-absorptive state (12 h or more after the last meal). Measurements were performed in a room at constant temperature (approximately 25°C). After entering the laboratory, subjects rested in the supine position for at least 30 min, and wore a face mask. In the case of overnight stay, the subjects were quietly awakened at 0700 and had a face mask attached while remaining in bed for 30 min. Two samples of expired air were collected in Douglas bags over each of two 10-min periods, and the mean of the two values was used for analysis.

Mass spectrometer (ARCO-1000 and ARCO-2000, Arco System, Kashiwa, Japan) were used to analyze the

Table 2. Predictive equations for basal metabolic rate used in the present study.

Predictive equations (kcal/d)	Age range	Males	Females
Japan-DRI (2010)	18–29	24.0×W	22.1×W
	30–49	22.3×W	21.7×W
	50–69	21.5×W	20.7×W
	70 over	21.5×W	20.7×W
Japan-DRI with adjustment for body weight	18–29	[24.0+(10.8−0.173×W)]×W	[22.1+(8.9−0.172×W)]×W
(Adjusted-DRI)	30–49	[22.3+(10.8−0.173×W)]×W	[21.7+(8.9−0.172×W)]×W
	50–69	[21.5+(10.8−0.173×W)]×W	[20.7+(8.9−0.172×W)]×W
	70 over	[21.5+(10.8−0.173×W)]×W	[20.7+(8.9−0.172×W)]×W
Harris-Benedict		66.4730+13.7516×W+5.0033×H −6.7550×A	655.0955+9.5634×W+1.8496×H −4.6756×A
Schofield	18–29	(0.063×W+2.896)×1.000/4.186	(0.062×W+2.036)×1,000/4.186
	30–59	(0.048×W+3.653)×1,000/4.186	(0.034×W+3.538)×1,000/4.186
	60 over	(0.049×W+2.459)×1,000/4.186	(0.038×W+2.755)×1,000/4.186
FAO/WHO/UNU	18–29	(64.4×W−113.0×H/100+3,000)/4.186	(55.6×W+1,397.4×H/100+146)/4.186
	30–59	(47.2×W+66.9×H/100+3,769)/4.186	(36.4×W−104.6×H/100+3,619)/4.186
	60 over	(36.8×W+4,719.5×H/100−4,481)/4.186	(38.5×W+2,665.2×H/100−1,264)/4.186
Ganpule		(0.0481×W+0.0234×H−0.0138×A −0.4235)×1,000/4.186	(0.0481×W+0.0234×H−0.0138×A −0.9708)×1,000/4.186

W: weight (kg), H: height (cm), A: age (y).

oxygen and carbon dioxide concentrations. The volume of expired air was determined using a dry gas volume meter (DC-5, Shinagawa, Tokyo, Japan) and converted to the volume under conditions of standard temperature, pressure, and dry gas (STPD). Gas exchange results were converted to BMR (kcal/d) using Weir's equation (*27*). To examine whether overnight stay before the BMR measurement caused a significant difference in the observed BMR, analysis of covariance with BMR as the dependent variable and gender, age, height, and body weight as covariates was employed. No significant effect of the measurement conditions was observed (stayed overnight: 1,275±15 kcal/d (mean±SE), came in the early morning on the day: 1,268±6 kcal/d (mean±SE), $F=0.163$, $p=0.687$).

Predictive equations of BMR. Predictive BMR was calculated using the Japan-DRI (*22*), Harris-Benedict (*11*), Schofield (*12*), FAO/WHO/UNU (*13*), and Ganpule (*25*) equations (Table 2). For the Japan-DRI equations, the Ministry of Health and Welfare proposed adjusting for the effect of body weight (*24*). Therefore, the equations with this adjustment (Adjusted-DRI) were also examined.

Statistical analysis. Results are presented as the mean±standard deviation (SD). Statistical significance was set at $p<0.05$ for all predictors. Differences between males and females were evaluated by an unpaired t-test. In addition to the mean±SD of the difference, total error (TE) was used to determine how accurately predicted BMR matched measured BMR. This statistic includes two sources of variation, one attributable to the lack of association between the two sets of measurement (standard error of estimate) and one attributable to the difference between the means (*28*). Statistical significance of differences between measured and predicted values was analyzed by one-way analysis of variance (ANOVA) and Dunnett's post hoc test. The relationship between difference of BMR (predicted minus measured BMR) and weight was examined using Pearson's correlation. Statistical analyses were performed using SPSS for Windows (version 15.0; SPSS Inc., Chicago, IL, USA).

Table 3. Measured basal metabolic rate (kcal/d and kcal/kg weight/d) in each sex and age group.

Age range	BMR (kcal/d) Mean±SD	BMR (kcal/kg weight/d) Mean±SD
Males (n=163)		
All	1,452±219	21.8±2.4
18–29	1,492±151	23.5±2.2
30–39	1,532±250	22.0±2.2
40–49	1,489±222	21.0±2.0
50–59	1,395±184	21.7±2.8
60–69	1,321±142	20.6±2.0
70–79	1,220±170	20.2±1.5
Females (n=202)		
All	1,122±136	21.2±2.4
18–29	1,132±122	22.2±2.6
30–39	1,168±122	21.6±2.4
40–49	1,196±161	21.3±1.9
50–59	1,090±114	19.6±1.8
60–69	1,085±110	20.1±1.7
70–79	968±107	20.1±1.9

RESULTS

The average weight and height of subjects in each age and gender group were comparable to national standard heights and weights (*29*) (Table 1). Average

Table 4. Predicted basal metabolic rate and mean differences from measured basal metabolic rate in males and females.

	Predicted BMR Mean±SD (kcal/d)	Mean differences±SD (kcal/d)	ANOVA *p* values	Post hoc test *p* values
Males (*n*=163)			<0.001	
Japan-DRI (2010)	1,504±258	53±155		0.080
Adjusted-DRI	1,428±109	−23±160		0.781
Harris-Benedict	1,550±223	99±132		<0.001
Schofield	1,607±186	155±142		<0.001
FAO/WHO/UNU	1,634±194	183±147		<0.001
Ganpule	1,480±174	28±122		0.628
Females (*n*=202)			<0.001	
Japan-DRI (2010)	1,148±178	26±122		0.161
Adjusted-DRI	1,122±88	0±96		1.000
Harris-Benedict	1,272±119	150±103		<0.001
Schofield	1,246±109	124±100		<0.001
FAO/WHO/UNU	1,254±111	132±98		<0.001
Ganpule	1,132±131	10±99		0.934

Mean differences: mean of difference between predicted and measured basal metabolic rate. Significance was determined by one-way ANOVA and Dunnett's post hoc test. Post hoc test *p* values: predicted vs. measured.

Table 5. Difference between the predicted and measured basal metabolic rate in each sex and age group.

Age range	*n*	Japan-DRI (2010) (kcal/d)	Adjusted-DRI (kcal/d)	Harris-Benedict (kcal/d)	Schofield (kcal/d)	FAO/WHO/UNU (kcal/d)	Ganpule (kcal/d)	ANOVA *p* values
Males (*n*=163)								
18–29	35	51±159	12±97	153±91*	168±98*	168±100*	25±87	<0.001
30–39	43	32±158	−90±188	131±134*	145±151*	187±151*	27±139	<0.001
40–49	34	101±157	−33±178	116±127*	201±138*	243±138*	41±126	<0.001
50–59	23	−2±131	−40±160	40±152	220±155*	263±155*	8±152	<0.001
60–69	16	68±173	34±110	29±110	23±108	57±112	38±108	0.774
70–79	12	80±89	90±105	−18±92	75±100	59±115	29±99	0.260
Females (*n*=202)								
18–29	80	9±136	0±105	211±95*	119±104*	120±105*	49±103*	<0.001
30–39	32	18±133	−21±91	143±89*	121±90*	132±89*	8±99	<0.001
40–49	26	31±101	−29±100	86±93	108±104*	121±102*	−41±83	<0.001
50–59	24	71±110	16±66	138±63*	211±65*	223±64*	23±65	<0.001
60–69	23	41±97	8±78	79±80*	67±77	97±83*	−37±84	<0.001
70–79	17	32±93	57±86	86±83*	129±86*	126±72*	−48±73	<0.001

Significance was determined by one-way ANOVA and Dunnett's post hoc test. *$p<0.05$ predicted vs. measured.

values of age, height, weight, and BMI were lower for females than for males. Table 3 shows measured BMR (kcal/d and kcal/kg weight/d) in males and females.

Tables 4 and 5 show predicted BMR. The mean values of BMR predicted by the Harris-Benedict equation, Schofield equation, and FAO/WHO/UNU equation were significantly higher than the measured BMR. Mean errors for equations developed for Japanese (Japan-DRI equation, Adjusted-DRI equation, and Ganpule equation) were smaller than those of internationally used equations (Harris-Benedict equation, Schofield equation, and FAO/WHO/UNU equation) in most age groups of both sexes. The mean errors of the predicted BMR by internationally used equations were significantly higher than the measured BMR in most age groups. However in the 60–69- and 70–79-y-old groups of males, the predicted BMR values were not significantly higher than the measured BMR.

TE values are shown in Table 6. TE of the Ganpule equation was low in both sexes (125 and 99 kcal/d, respectively). In addition, TE using the Adjusted-DRI equation was low in females (95 kcal/d). On the other hand, TE of the Japan-DRI equation was 163 kcal/d in males and 124 kcal/d in females, TE of the Adjusted-DRI equation was 162 kcal/d in males. TE values were higher for other equations than for equations developed for Japanese. In particular, TE of the FAO/WHO/UNU equation was largest in males and that of the Harris-Benedict equation was largest in females. In males, TE of the Ganpule equation was the lowest in all age categories except those over 60 y old. In males, the TE of the FAO/WHO/UNU equation was 278 kcal/d in the 40–49-y-old group, and those of the Schofield and FAO/WHO/UNU equations were higher in the 50–59-y-old

Table 6. Total errors of the prediction equations for basal metabolic rate in each sex and age group.

Age range	n	Japan-DRI (2010)	Adjusted-DRI	Harris-Benedict	Schofield	FAO/WHO/UNU	Ganpule
Males							
All	163	163	162	165	210	234	125
18–29	35	164	97	177	194	194	90
30–39	43	160	206	186	208	239	140
40–49	34	185	179	171	243	278	131
50–59	23	170	161	154	267	303	149
60–69	16	144	112	110	107	123	111
70–79	12	117	135	90	122	125	99
Females							
All	202	124	95	182	159	165	99
18–29	80	136	105	231	158	159	114
30–39	32	132	92	168	150	158	98
40–49	26	104	102	125	149	157	91
50–59	24	129	67	151	220	232	68
60–69	23	104	77	111	101	127	90
70–79	17	96	101	118	154	144	86

$$\text{Total error (kcal/d)} = \frac{\Sigma(\text{predicted BMR} - \text{measured BMR})^2}{n}.$$

group than the other predictive equations (267 and 303 kcal/d, respectively), as these equations grossly overestimated BMR in these subjects. In females, the TE values of the Adjusted-DRI and Ganpule equations were low. The TE of the Harris-Benedict equation was highest in 18–29-y-old females. In 50–59-y-old females, the TE values of the Schofield and FAO/WHO/UNU equations were higher than those of the other predictive equations (220 and 232 kcal/d, respectively).

Relationship between the difference of BMR (predicted minus measured BMR) and weight is shown in Fig. 1. The difference was significantly correlated with body weight positively for Japan DRI equations in both sexes and Harris-Benedict equation in males and negatively for Adjusted DRI equations in both sexes and Harris-Benedict equation in females. For the Schofield, FAO/WHO/UNU, and Ganpule equations, there was no significant correlation between the prediction error and body weight.

DISCUSSION

The Japan-DRI equation, Adjusted-DRI equation, and Ganpule equation for both sexes predicted BMR relatively accurately, while the internationally adopted equations of Harris-Benedict equation, Schofield equation, and FAO/WHO/UNU equation overestimated BMR. The prediction error by Japan-DRI, Adjusted-DRI, and Harris-Benedict equation was significantly correlated with body weight in both sexes. The present study suggests that the Ganpule equation is likely to be the most accurate in predicting the BMR of healthy Japanese, because the TE and mean difference between predicted and measured BMR were relatively small in many sex and age groups, and weight had no effect on the predicted error.

The most important innovation of the present study is that the validity of various predictive equations for BMR, including the Japan-DRI and Ganpule equations was examined in sex and age groups of larger size. Values of BMR in young healthy Japanese females and in a few other age groups of Japanese have been reported (*30*, *31*), but there has been no recent report evaluating the validity of predictive equations for BMR in healthy Japanese subjects.

Japan-DRI equations were developed based on the data for Japanese subjects with standard body size 50 y ago. Although body composition may have changed in the interim (*30*), these earlier values are still being used. Schofield equations and FAO/WHO/UNU equations were developed based on data from a population of many races (*12–14*). However, the data used to develop the Schofield equation were mostly from young European military and police recruits, including 2,279 males and 247 females, with 45% being of Italian descent. Although the age range of the study sample was 19 to 82 y, the elderly were minimally represented (*32*). Average BMR values were reported to be higher in these Italians than in other Caucasian study participants (*33*, *34*). The data of only 53 young Japanese adults reported in 1926 were included in the database (*16*). Asians are reported to have lower BMR than Europeans by 10–12% (*35*), even after adjustment for body composition. Harris-Benedict equations were developed using data obtained in healthy normal weight Caucasian males (n=136) aged 16–63 y and females (n=103) aged 15–74 y, including only three males and six females over 60 y old. Although in each age group and in the female group, the subjects used to evaluate the Harris-Benedict equation and those used in the present study were of comparable average weight and height, the average difference in BMR between these studies (Harris-Benedict and the present study) was about 200 kcal/d, and the mean error of the Harris-Benedict estimate was 211 kcal/d in the present study.

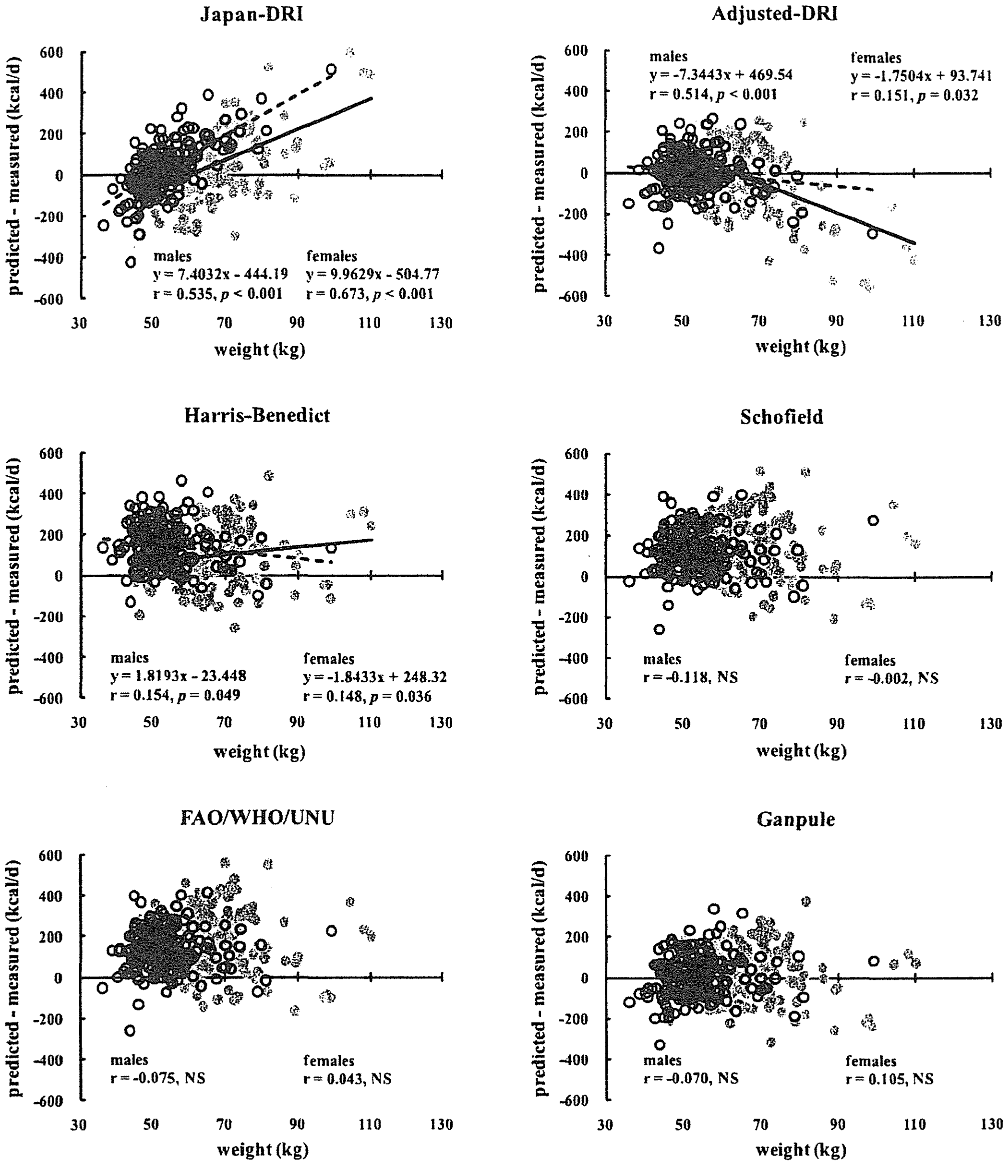

Fig. 1. Relationship between difference of basal metabolic rate (predicted minus measured basal metabolic rate) and weight in males and females. Males, black circle (●) and straight line (——); females, white circle (○) and dashed line (- - -).

Harris-Benedict equations have been criticized for including a few obese subjects (mean BMI 21.4±2.9 kg/m^2 in males, 21.5±4.1 kg/m^2 in females), for having inadequate representation at the young and old extremes of age, and for having a systematic error of 5 to 15% (*36*). The Ganpule equation was recently developed using data from 137 healthy Japanese adults and the standard error of estimate of the regression analysis was low (prediction error=7.3%).

The Japan-DRI equation overestimated BMR by 100 kcal/d or less in most age groups (Tables 4 and 5). The recently reported difference between values predicted by the Japan-DRI equation and measured values for young healthy Japanese females was 70 kcal/d (*30*). The mean difference from measured values was lower for the Adjusted-DRI and Ganpule equations than for the Japan-DRI equation in most age groups of females. Mean difference and TE values were smaller using the Japan-DRI equations, Adjusted-DRI equations, and Ganpule equation than the internationally used equations (Harris-Benedict, Schofield, FAO/WHO/UNU) in both sexes (Tables 4–6). In particular, the TE was lower for the Ganpule equation than the other equations in most age groups in males except in the 60–69- and 70–79-y-old groups. On the other hand, TE values for the Adjusted-DRI equation and Ganpule equation were small in females. The values of Adjusted-DRI equation and Ganpule equation in females were comparable in the 18–69-y-old female groups. TE in 18–29-y-old females was higher for the Harris-Benedict equation than for the other equations, mainly due to the large mean error between predicted and measured values, and not due to the SD. The TE for the Schofield equation and FAO/WHO/UNU equation were high, especially in 40–59-y-old males. Thus, these internationally used equations are inadequate for healthy Japanese subjects.

The equations currently recommended for international use have been reported to overestimate BMR in some previous studies. For Caucasians, the Harris-Benedict equation overestimated the BMR of healthy females by 14–24% (*17, 18*). On the other hand, the Harris-Benedict equation overestimated BMR by 8–19% in healthy Chinese adults (*37*). Case et al. (*9*) reported that the Harris-Benedict equation and FAO/WHO/UNU equation overestimated BMR by about 100 kcal/d in 36 Asian females including Japanese females. Ganpule et al. (*25*) and Yamamura and Kashiwazaki (*31*) showed that FAO/WHO/UNU equations overestimated BMR in Japanese subjects to a similar degree. Thus, these internationally used equations have been reported to overestimate BMR for Asians including Japanese. The results in the present study were comparable to those of previous studies in general, while the mean error of the Harris-Benedict estimates was smaller in the present study. TE values for the Harris-Benedict equation and Ganpule equation were comparable in the 70–79-y-old male group. Melzer et al. (*6*) reported that the Harris-Benedict equation showed the lowest mean error (−41 kcal/d) in elderly healthy Caucasian adults. Therefore, the Harris-Benedict equation may be used for elderly Japanese females because its TE was smaller in the over-60-y-old groups than in other age groups. However, the TE was larger in young females for the Harris-Benedict equation than for the other equations. Thus, the use of the Harris-Benedict equation is inappropriate for all patients in clinical settings. The reason that prediction by Harris-Benedict equation is relatively accurate only for elderly females is unclear. It should be noted that there are gender differences between the coefficients for body weight, height, and age in these equations. The intercept is much larger for females than for males (655.1 vs. 66.47) and the other coefficients are smaller for females than for males.

The mean differences in BMR between the Japan-DRI in both sexes and Adjusted-DRI equations in males were highly influenced by weight. For individuals with larger body weight, the difference between predicted BMR by Japan-DRI equations and measured BMR was larger in both sexes, while the difference by Adjusted-DRI equations was smaller and negative in males with larger body weight. For Harris-Benedict equations in both sexes and the Adjusted-DRI equation in females, the effect of body weight on the prediction error was small but significant, as also reported by Tanaka et al. (*38*) for obese subjects. Yamamura and Kashiwazaki (*31*) reported that, for lean subjects ($\text{BMI} \leq 18.4\ \text{kg/m}^2$) over 18 y old, the difference between the observed and predicted values (calculated by the Japan-DRI equation) was higher than the predicted values (calculated by the other equations). In contrast, the difference was less for normal-weight subjects ($18.5\ \text{kg/m}^2 \leq \text{BMI} \leq 24.9\ \text{kg/m}^2$). Japan-DRI equations are just multiple of body weight, and do not have an intercept term. It is inappropriate to express metabolic rate data per body weight or per kg of fat-free mass, as the relationship between metabolic rate and body weight or fat-free mass has an intercept significantly different from zero (*39*). Therefore, systematic error can be expected (*39*) and some adjustments for body size are needed when using Japan-DRI equations. However, the adjustment for body weight in the Adjusted-DRI equation was adequate for females but not for males (Fig. 1). Adequate adjustment of the coefficients may decrease the prediction errors. For the Ganpule, Schofield, and FAO/WHO/UNU equations, weight had no effect in either sex. The Ganpule equation can be used for all age groups of Japanese, because the TE and mean difference between predicted and measured BMR are small, and weight has no effect on the prediction error.

The present study examined the validity of predictive equations for BMR. The conditions of BMR measurement must be considered. Historically, BMR was defined as the energy expenditure of an individual 12 h after the last meal while that individual lay quietly at rest at normal ambient and body temperatures and in the absence of either physical or psychological stress (*11, 23*). However, in most reports about Harris and Benedict (*11*), Schofield (*12*), FAO/WHO/UNU (*13*), and Japan-DRI equations, subjects were permitted to walk or ride to a laboratory early on the morning of testing, and expired air was collected after quiet rest for about 30 min. Berke et al. (*40*) found that for elderly people, the resting metabolic rate was higher in outpatient condition than in inpatient condition. On the other hand, Turley et al. (*41*) found no difference in BMR measured in the morning after an overnight clinic stay and BMR measured in the morning after 30 min of rest after traveling by car from home. In Japan, most of the BMR values measured at Nagasaki University, Tokushima University, or Showa Medical University in the 1950s–1960s were not obtained after an overnight stay (*23*), and the Japan-DRI equation was created using these data. The Schofield and FAO/WHO/UNU equations were developed using BMR measurements from many reports, and much of the BMR data was not obtained after an overnight stay (*12*). Likewise, the BMR data used to develop the Harris-Benedict equation were not obtained after an overnight stay (*11*).

The most important limitation of the present study is that body composition was not measured. Weight and height, which can be easily obtained in clinical as well as epidemiological settings, were used. In general, body weight affects BMR. However, the relatively large prediction errors by the Harris-Benedict, Schofield, and FAO/WHO/UNU equations may be due to difference in the body composition between subjects in the present study and subjects in the original studies (*42*). Cunningham (*43*) reported that lean body mass was the only predictor of BMR. Although body weight, height, age, and sex can account for variance in BMR as well as body composition (*25, 37*), body composition data might have helped interpret the results of the present study.

Our findings indicate that the Ganpule estimates of BMR are the most accurate in healthy Japanese subjects. BMR per body weight can only be used for prediction of BMR in individuals of normal weight.

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Validation and Comparison of 3 Accelerometers for Measuring Physical Activity Intensity During Nonlocomotive Activities and Locomotive Movements

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Background: The current study evaluated the validity of 3 commercially-available accelerometers to assess metabolic equivalent values (METs) during 12 activities. ***Methods:*** Thirty-three men and thirty-two women were enrolled in this study. The subjects performed 5 nonlocomotive activities and 7 locomotive movements. The Douglas bag method was used to gather expired air. The subjects also wore 3 hip accelerometers, a Lifecorder uniaxial accelerometer (LC), and 2 triaxial accelerometers (ActivTracer, AT; Actimarker, AM). ***Results:*** For nonlocomotive activities, the LC largely underestimated METs for all activities (20.3%–55.6%) except for desk work. The AT overestimated METs for desk work (11.3%) and hanging clothes (11.7%), but underestimated for vacuuming (2.3%). The AM underestimated METs for all nonlocomotive activities (8.0%–19.4%) except for hanging clothes (overestimated by 16.7%). The AT and AM errors were significant, but much smaller than the LC errors (23.2% for desk work and –22.3 to –55.6% for the other activities). For locomotive movements, the 3 accelerometers significantly underestimated METs for all activities except for climbing down stairs. ***Conclusions:*** We conclude that there were significant differences for most activities in 3 accelerometers. However, the AT, which uses separate equations for nonlocomotive and locomotive activities, was more accurate for nonlocomotive activities than the LC.

Keywords: algorithm, metabolic equivalents, daily activity

It is well known that physical fitness and activity confer numerous health benefits in the prevention of lifestyle-related diseases.[1,2] Physical activity energy expenditure (PAEE) can be divided into exercise-related activity thermogenesis and nonexercise activity thermogenesis (NEAT), with the latter consisting mainly of energy expenditure (EE) of low-to-moderate intensity during lifestyle activities.[3] Levine et al suggested that the EE due to NEAT, including nonlocomotive activity, is much larger than EE due to exercise throughout the day and may be an important factor in the prevention of obesity.[4] Therefore, it is important to estimate EE of daily activities, including locomotive movements and nonlocomotive activities such as household tasks and occupational activities. As Westerterp indicates, PAEE of nonlocomotive activities accounts for more than 50% of total PAEE.[5]

Recently, various types of small and lightweight accelerometers have become available for assessing the amount and intensity of physical activity (PA). However, these devices use different algorithms, which depend on the number of axes (uni- or triaxial) and predictive equations for PAEE and intensity.[6] The usefulness of the Kenz Lifecorder EX (LC; SUZUKEN Co., Ltd., Nagoya, Japan), a uniaxial accelerometer widely used in Japan, for assessing PA intensity and PAEE during locomotive movements such as walking and jogging has been reported.[7,8] However, total energy expenditure (TEE) calculated from the LC data significantly underestimated by 20%–35% the TEE measured by the doubly labeled water method in Japanese men.[9,10] We speculate that the most important reason for this underestimation is related to the algorithm of the LC accelerometer, which was designed to assess PA intensity during ambulation. The LC device determines PA intensity from the frequency of steps and the degree of vertical acceleration.[11] However, if some PA such as household work does not involve a sufficient number of steps, the LC instrument may not be able to accurately assess PA intensity.

Triaxial accelerometers have also become popular devices for assessing PA intensity.[12–14] Nevertheless, Hendelman et al indicated that the regression equation used to predict metabolic equivalent (MET) values based on locomotive movements had a different slope and intercept compared with regression equation based on nonlocomotive activities.[12] Thus, when an equation based on locomotive movements is used to predict MET values for nonlocomotive activities and ambulation, there could be large prediction errors. Midorikawa et al tried to resolve

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