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Validity of Predictive Equations for Basal Metabolic Rate in Japanese Adults

Rieko MIYAKE[1,2], Shigeho TANAKA[1,*], Kazunori OHKAWARA[1], Kazuko ISHIKAWA-TAKATA[1], Yuki HIKIHARA[3], Emiko TAGURI[2,4], Jun KAYASHITA[5] and Izumi TABATA[1,6]

[1] *Department of Health Promotion and Exercise, National Institute of Health and Nutrition, 1–23–1 Toyama, Shinjuku-ku, Tokyo 162–8636, Japan*
[2] *Graduate School of Humanities and Sciences, Ochanomizu University, Tokyo 112–8610, Japan*
[3] *Faculty of Engineering, Chiba Institute of Technology, Narashino 275–0023, Japan*
[4] *Health Insurance Naruto Hospital, Tokushima 772–8503, Japan*
[5] *Graduate School of Comprehensive Scientific Research, Prefectural University of Hiroshima, Hiroshima 734–8558, Japan*
[6] *Faculty of Sport and Health Sciences, Ritsumeikan University, Shiga 525–8577, Japan*

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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

*To whom correspondence should be addressed.
E-mail: tanakas@nih.go.jp

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

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.

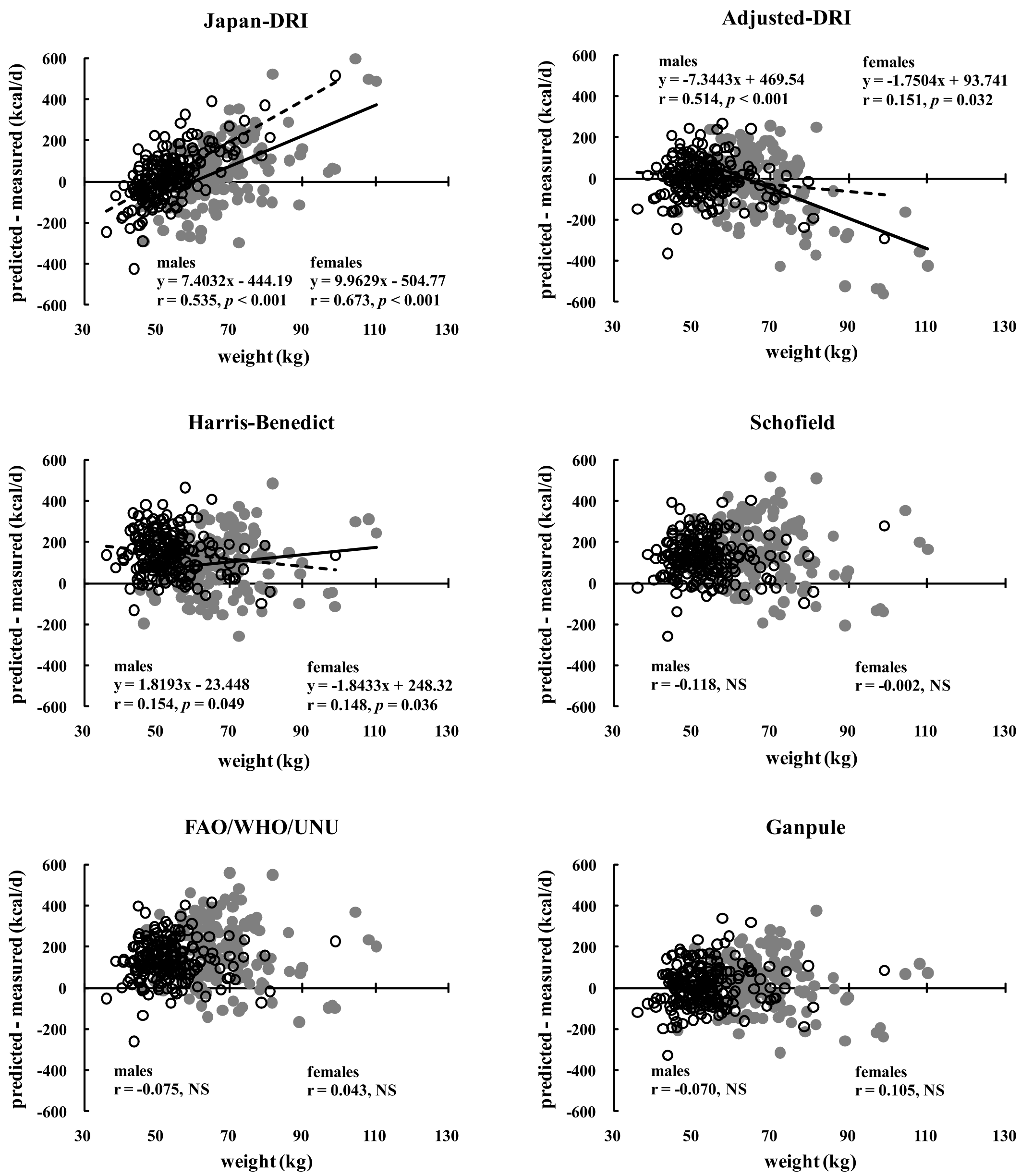

Fig. 1. Relationship between difference of basal metabolic rate (predicted minus measured basal metabolic rate) and weight in males and females. Males, black circle (●) and straight line (——); females, white circle (○) and dashed line (- - -).

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 (BMI≤18.4 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 kg/m^2≤BMI≤24.9 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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