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.

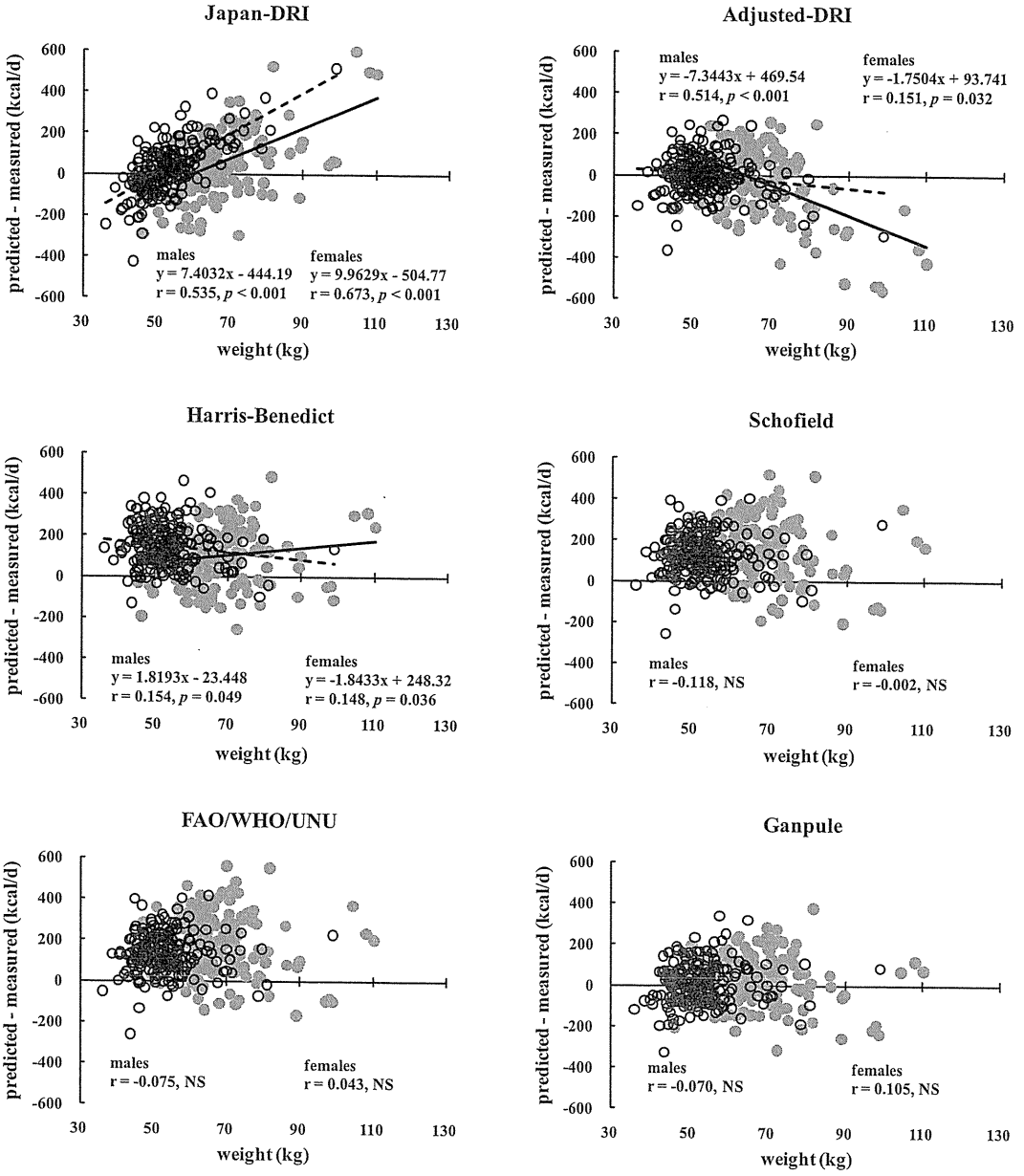

Fig. 1. Relationship between difference of basal metabolic rate (predicted minus measured basal metabolic rate) and weight in males and females. Males, black circle (●) and straight line (——); females, white circle (○) and dashed line (- - -).

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 predic-

tion of BMR in individuals of normal weight.

Acknowledgments

We express our heartfelt thanks to the subjects who participated in the present study. We thank the members of the National Institute of Health and Nutrition, especially Ms Hiroko Kogure, for their help in data acquisition and analyses.

REFERENCES

1) Institute of Medicine of the National Academies. 2005. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty, Acids, Cholesterol, Protein and Amino Acids. p 4. The National Academies Press, Washington DC.
2) Levine JA. 2005. Measurement of energy expenditure. *Public Health Nutr* **8**(7A): 1123–1132.
3) Ishikawa-Takata K, Tabata I, Sasaki S, Rafamantanantsoa HH, Okazaki H, Okubo H, Tanaka S, Yamamoto S, Shirota T, Uchida K, Murata M. 2008. Physical activity level in healthy free-living Japanese estimated by doubly labelled water method and International Physical Activity Questionnaire. *Eur J Clin Nutr* **62**: 885–891.
4) Westerterp KR. 2003. Impacts of vigorous and non-vigorous activity on daily energy expenditure. *Proc Nutr Soc* **62**: 645–650.
5) Reeves MM, Capra S. 2003. Predicting energy requirements in the clinical setting: Are current methods evidence based? *Nutr Rev* **61**: 143–151.
6) Melzer K, Laurie Karsegard V, Genton L, Kossovsky MP, Kayser B, Pichard C. 2007. Comparison of equations for estimating resting metabolic rate in healthy subjects over 70 years of age. *Clin Nutr* **26**: 498–505.
7) Merritt R. 1998. The A.S.P.E.N. Nutrition Support Practice Manual, Chapter 2. American Society for Parenteral & Enteral Nutrition, Maryland.
8) Inoue Y, Yoshida S, Tabira Y, Omura K, Fukushima R, Ikeda K, Ohyanagi H, Ogoshi S. 2004. Recent trend in clinical practice of nutritional support in Japan—The results of a national survey 2002. *JSPEN* **19**: 37–43 (in Japanese).
9) Case KO, Brahler CJ, Heiss C. 1997. Resting energy expenditures in Asian women measured by indirect calorimetry are lower than expenditures calculated from prediction equations. *J Am Diet Assoc* **97**: 1288–1292.
10) Leung R, Woo J, Chan D, Tang N. 2000. Validation of prediction equations for basal metabolic rate in Chinese subjects. *Eur J Clin Nutr* **54**: 551–554.
11) Harris JA, Benedict FG. 1919. A Biometric Study of Basal Metabolism in Man. Carnegie Institute of Washington, Washington DC.
12) Schofield WN. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* **39C**: 5–41.
13) FAO/WHO/UNU. 1985. Energy and Protein Requirements, Report of a Joint FAO/WHO/UNU Expert Consultation. Technical Report Series 724. WHO, Geneva.
14) Schofield C. 1985. An annotated bibliography of source material for basal metabolic rate data. *Nutr Clin Nutr* **39C**: 42–91.
15) Reeves MM, Capra S. 2003. Predicting energy requirements in the clinical setting: Are current methods evidence based? *Nutr Rev* **61**: 143–151.
16) Okada S, Sakurai E, Kameda T. 1926. The basal metabolism of the Japanese. *Arch Intern Med* **38**: 590–602.
17) Daly JM, Heymsfield SB, Head CA, Harvey LP, Nixon DW, Katzeff H, Grossman GD. 1985. Human energy requirements: overestimation by widely used prediction equation. *Am J Clin Nutr* **42**: 1170–1174.
18) Owen OE, Kavle E, Owen RS, Polansky M, Caprio S, Mozzoli MA, Kendrick ZV, Bushman MC, Boden G. 1986. A reappraisal of the caloric requirements in healthy woman. *Am J Clin Nutr* **44**: 1–19.
19) Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, Kavle EC, Bushman MC, Owen LR, Mozzoli MA, Kendrick ZV, Boden GH. 1987. A reappraisal of the caloric requirements of man. *Am J Clin Nutr* **46**: 875–885.
20) Miffilin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. 1990. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr* **51**: 241–247.
21) Henry CJK, Rees DG. 1991. New predictive equations for the estimation of basal metabolic rate in tropical peoples. *Eur J Clin Nutr* **45**: 177–185.
22) Ministry of Health, Labour and Welfare of Japan. 2009. Dietary Reference Intakes for Japanese, 2010. Daiichi Shuppan, Tokyo (in Japanese).
23) Yamamoto S, Komatsu T. 2001. Evaluation of the data on basal metabolic rate for Japanese. *Jpn J Nutr Diet* **59**: 51–59 (in Japanese).
24) Ministry of Health and Welfare, Japan. 1975. Recommended Dietary Allowances for the Japanese, revision in 1975. Daiichi Shuppan, Tokyo (in Japanese).
25) Ganpule AA, Tanaka S, Ishikawa-Takata K, Tabata I. 2007. Interindividual variability in sleeping metabolic rate in Japanese subjects. *Eur J Clin Nutr* **61**: 1256–1261.
26) Lohman TG, Roche AF, Martorell R. 1988. Anthropometric Standardization Reference Manual. Human Kinetic Books, Champaign.
27) Weir JB. 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* **109**: 1–9.
28) van der Ploeg GE, Gunn SM, Withers RT, Modra AC, Keeves JP, Chatterton BE. 2001. Predicting the resting metabolic rate of young Australian males. *Eur J Clin Nutr* **55**: 145–152.
29) Ministry of Health, Labour and Welfare of Japan. 2010. The National Health and Nutrition Survey in Japan, 2007. Daiichi Shuppan, Tokyo (in Japanese).
30) Takahashi E, Higuchi M, Hosokawa Y, Tabata I. 2007. Basal metabolic rate and body composition of Japanese young adult females. *Jpn J Nutr Diet* **65**: 241–247 (in Japanese).
31) Yamamura C, Kashiwazaki H. 2002. Factors affecting the post-absorptive resting metabolic rate of Japanese subjects: reanalysis based on published data. *Jpn J Nutr Diet* **60**: 75–83 (in Japanese).
32) Frenkenfield D, Roth-Yousey L, Compher C. 2005. Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. *J Am Diet Assoc* **105**: 775–789.
33) Shetty P. 2005. Energy requirements of adults. *Public Health Nutr* **8**(7A): 994–1009.
34) Henry CJK. 2005. Basal metabolic rate studies in humans: measurement and development of new equations. *Public Health Nutr* **8**(7A): 1133–1152.
35) Hayter JE, Henry CJK. 1994. A re-examination of basal

metabolic rate predictive equations: the importance of geographic origin of subjects in sample selection. *Eur J Clin Nutr* **48**: 702–707.

36) Frankenfield DC, Rowe WA, Smith JS, Cooney RN. 2003. Validation of several established equations for resting metabolic rate in obese and nonobese people. *J Am Diet Assoc* **103**: 1152–1159.

37) Liu HY, Lu YF, Chen WJ. 1995. Predictive equations for basal metabolic rate in Chinese adults: a cross-validation study. *J Am Diet Assoc* **95**: 1403–1408.

38) Tanaka S, Ohkawara K, Ishikawa-Takata K, Morita A, Watanabe S. 2008. Accuracy of predictive equations for basal metabolic rate and the contribution of abdominal fat distribution to basal metabolic rate in obese Japanese people. *Anti-Aging Med* **5**: 17–21.

39) Ravussin E, Bogardus C. 1989. Relationship of genetics, age, and physical fitness to daily energy expenditure and fuel utilization. *Am J Clin Nutr* **49**: 968–975.

40) Berke EM, Gardner AW, Goran MI, Poehlman ET. 1992. Resting metabolic rate and the influence of the pretesting environment. *Am J Clin Nutr* **55**: 626–629.

41) Turley KR, McBride PJ, Wilmore JH. 1993. Resting metabolic rate measured after subjects spent the night at home vs at a clinic. *Am J Clin Nutr* **58**: 141–144.

42) Wouters-Adriaens MP, Westerterp KR. 2008. Low resting energy expenditure in Asians can be attributed to body composition. *Obesity* **16**: 2212–2216.

43) Cunningham JJ. 1991. Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. *Am J Clin Nutr* **54**: 963–969.

J Nutr Sci Vitaminol, **57**, 348–354, 2011

Obese Japanese Adults with Type 2 Diabetes Have Higher Basal Metabolic Rates than Non-Diabetic Adults

Rieko MIYAKE, Kazunori OHKAWARA, Kazuko ISHIKAWA-TAKATA, Akemi MORITA, Shaw WATANABE and Shigeho TANAKA

J Nutr Sci Vitaminol, 57, 348–354, 2011

Obese Japanese Adults with Type 2 Diabetes Have Higher Basal Metabolic Rates than Non-Diabetic Adults

Rieko MIYAKE[1,2], Kazunori OHKAWARA[1], Kazuko ISHIKAWA-TAKATA[1], Akemi MORITA[1], Shaw WATANABE[1] and Shigeho TANAKA[1,*]

[1]*National Institute of Health and Nutrition, Tokyo 162–8636, Japan*
[2]*Graduate School of Humanities and Sciences, Ochanomizu University, Tokyo 112–8610, Japan*

(Received March 18, 2011)

Summary Several cross-sectional studies in Pima Indians and Caucasians have indicated that obese individuals with type 2 diabetes have a higher basal metabolic rate (BMR) than healthy, obese individuals. However, no study has investigated this comparison in Japanese subjects, who are known to be susceptible to type 2 diabetes due to genetic characteristics. Thirty obese Japanese adults with pre-type 2 diabetes ($n=7$) or type 2 diabetes ($n=13$) or without diabetes ($n=10$) participated in this study. BMR was measured using indirect calorimetry. The relationships between residual BMR (calculated as measured BMR minus BMR adjusted for fat-free mass, fat mass, age, and sex) and biomarkers including fasting glucose, glycosylated hemoglobin (HbA_{1c}), fasting insulin, homeostasis model assessment of insulin resistance (HOMA-R), triglycerides, and free fatty acids were examined using Pearson's correlation. BMR in diabetic subjects adjusted for fat-free mass, fat mass, age, and sex was 7.1% higher than in non-diabetic subjects. BMR in diabetic subjects was also significantly ($p<0.05$) higher than in non-diabetic subjects. There was a significant correlation between residual BMR and fasting glucose ($r=0.391$, $p=0.032$). These results indicate that in the Japanese population, obese subjects with type 2 diabetes have higher BMR compared with obese non-diabetic subjects. The fasting glucose level may contribute to these differences.

Key Words basal metabolic rate, Japanese, obesity, diabetes, predictive equation

As type 2 diabetes and obesity are closely related, the number of patients with type 2 diabetes in Japan has increased as a result of the rise in prevalence of obesity (*1*). In general, the fundamental treatment for type 2 diabetes is improvement in lifestyle such as diet and physical activity, associated with pharmacotherapy (*2*). Control of daily energy balance remains one of the most important treatment principles. Management of daily energy balance is usually conducted by diet control and maintenance of higher levels of physical activity. Accurate assessments of energy intake and energy expenditure are therefore required during treatment of diabetes.

Several cross-sectional studies have examined whether or not individuals with type 2 diabetes have a higher basal metabolic rate (BMR). Previous studies in Pima Indians (*3*) and Caucasians (*4*) using calorimetry showed obese subjects with type 2 diabetes had 5.2% and 6.9% higher BMR, adjusted for body composition, compared with their respective non-diabetic counterparts. Although the physiological mechanisms responsible for the increased BMR in individuals with type 2 diabetes are poorly understood, several mechanisms have been proposed to explain this change in BMR. These include increases in protein turnover (*5*), futile substrate cycling (*6*), gluconeogenesis (*7*), plasma glucagon (*8*), and sympathetic nervous system activity (*3*). As Japanese people are susceptible to type 2 diabetes (*9*), mainly due to a lower ability to secrete insulin than Caucasians (*10*), this genetic characteristic may provide different results in BMR than similar studies in Pima Indians or Caucasians (*3*, *4*). However, no study has examined whether BMR is higher in Japanese subjects with type 2 diabetes compared to subjects without diabetes.

As BMR may be different between individuals with non-diabetes, pre-diabetes or diabetes, some adjustments may be necessary when BMR is calculated in these groups. As the majority of clinical facilities are unable to carry out indirect calorimetry, BMR is usually estimated from predictive equations using data including age, sex, height, and weight (*11*). Previous studies indicate that predictive equations derived mainly from measurements in Caucasian subjects tend to overestimate BMR in both Asians (*11*, *12*) and Caucasians (*11*, *13–17*). We recently developed new predictive equations for BMR in the Japanese population (*18*). One of these equations was shown to be the best predictor of BMR amongst several predictive equations in healthy Japanese subjects (*19*). However, no study has investigated the validity of several of these published equations in Japanese subjects with type 2 diabetes.

The purpose of the present study was therefore to compare BMR between subjects with non-diabetes, pre-diabetes or diabetes in the obese Japanese population.

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

Table 1. Physical characteristics and metabolic parameters in subjects with non-diabetes, pre-diabetes, or diabetes.

	Non-diabetes (n=10)		Pre-diabetes (n=7)		Diabetes (n=13)		ANOVA p value
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	
Male/female	5/5		3/4		8/5		
Age (y)	54±3	51–59	53±3	50–57	53±3	50–59	0.760
Height (cm)	165.3±10.0	151.5–179.2	162.9±7.7	155.0–174.0	165.3±8.7	152.0–176.6	0.826
Weight (kg)	81.1±7.2	69.3–93.5	82.0±10.7	67.0–97.7	87.4±12.4	70.2–116.5	0.317
Body mass index (kg/m^2)	29.7±1.7	27.7–33.2	30.9±3.3	27.9–38.0	32.0±3.5	28.1–39.2	0.211
Body fat (%)	33.7±7.4	24.0–45.4	36.3±8.9	23.4–45.6	36.5±6.6	24.0–46.0	0.627
FM (kg)	26.9±4.5	21.2–34.5	29.5±8.0	20.9–44.6	31.7±6.2	23.1–45.7	0.206
FFM (kg)	54.1±10.2	41.6–71.1	52.4±11.4	40.8–68.5	55.8±11.2	41.6–73.0	0.808
Fasting glucose (mg/dL)	99±5	92–109	111±10	90–121	130±17[a,b]	100–168	<0.001
Log$_e$ HbA_{1c}	1.8±0.0	1.7–1.8	1.8±0.1	1.7–1.9	1.9±0.2[a]	1.6–2.5	0.016
[HbA_{1c} (%)]	5.9	5.7–6.0	5.9	5.4–6.4	7.1	5.0–12.6	
Log$_e$ fasting insulin	1.8±0.4	1.0–2.3	2.5±0.7[a]	1.5–3.3	2.3±0.6	1.5–3.5	0.019
[Fasting insulin (μU/mL)]	6.5	2.8–10.1	14.9	4.4–27.4	12.1	4.3–33.8	
HOMA-R	1.6±0.6	0.7–2.5	4.1±2.4	1.3–8.2	3.8±2.7	1.5–11.8	0.030
Triglycerides (mg/dL)	149±66	76–268	221±119	87–410	153±89	51–384	0.221
Free fatty acid (mEq/L)	0.4±0.2	0.1–0.7	0.5±0.1	0.4–0.7	0.5±0.2	0.3–1.0	0.339

FM: fat mass. FFM: fat-free mass. HbA_{1c}: glycosylated hemoglobin. HbA_{1c} and fasting insulin were log transformed. HOMA-R=fasting insulin×fasting glucose/405. Differences between the non-diabetes, pre-diabetes and diabetes groups were evaluated by one-way ANOVA and Bonferroni post hoc test. [a]$p<0.05$ vs. non-diabetes, [b]$p<0.05$ vs. pre-diabetes.

The second aim of the study was to examine the validity of several predictive equations for BMR in these subjects.

MATERIALS AND METHODS

Subjects. The subjects in the study were 50- to 59-y-old obese subjects who resided in Saku City (Nagano Prefecture in Japan). The subjects were selected randomly from participants in the Saku Control Obesity Program (SCOP). The details of SCOP are described elsewhere (*20*). Thirty obese Japanese adults without diabetes (n=10), or with pre-type 2 diabetes (n=7) or type 2 diabetes (n=13) participated in this study. Two diabetic patients were treated by diet and exercise prescription, and one diabetic patient by metformin or glibenclamide therapy. Another diabetic patient who had experienced a diabetes patient education program in the past was included also, whereas those on insulin therapy were excluded. The subjects were instructed to eat a usual diet and carry out normal, but not vigorous physical activity beginning 1 d before the measurements. All the investigations were carried out in the Saku Central Hospital. This study was conducted according to the guidelines of 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 and the Ethical Committee of the Saku Central Hospital. The study protocol was explained to the subjects prior to enrollment, and all the subjects signed an informed consent form.

Anthropometric and body composition. The physical characteristics of the subjects are summarized in Table 1. Body weight was measured to the nearest 0.1 kg and body height to the nearest 0.1 cm using an automatic scale (Tanita, BF-220, Tokyo, Japan). The measurements were performed in light clothing and underwear. The light clothing was then 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). Percentage body fat was measured using a bioelectrical impedance technique (Tanita, BF-220). Fat-free mass (FFM) and fat mass (FM) were calculated from percentage body fat and body weight.

Measurements of BMR. The subjects came to the hospital in the early morning and were asked to minimize walking prior to the laboratory visit and BMR measurement. In the majority of previous studies, especially in those using the dietary reference intakes for Japanese (Japan-DRI), Schofield, or the Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University, the subjects also came to the laboratory in the early morning (*21*). BMR was measured in the post-absorptive state at least 12 h after the last meal. Measurements were performed in a room at a constant temperature of approximately 25°C. After entering the hospital, the subjects rested in the supine position wearing a face mask for at least 30 min. Two samples of expired air were collected in Douglas bags over two 10-min periods, and the mean of the two values used in the analyses.

The expired air was sampled and the O_2 and CO_2 concentrations measured using a gas analyzer (Arco System, AR-1, Kashiwa, Japan) with a galvanic O_2 sensor and an infrared CO_2 sensor. Prior to each of the consecutive measurements, the gas analyzer was calibrated using atmospheric air. The volume of expired air was

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

Predictive equations (kcal/d)		
	Males	Females
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
Japan-DRI (2010)	21.5 ×W	20.7 ×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	(0.048×W+3.653)×1,000/4.186	(0.034×W+3.538)×1,000/4.186
Owen	879+(10.20×W)	795+(7.18×W)
Mifflin	5+(9.99×W)+(6.25×H)−(4.92×A)	−161+(9.99×W)+(6.25×H)−(4.92×A)

W: weight (kg), H: height (cm), A: age (y). Predictive equations for 50- to 59-y old obesity subjects were used.

determined using a dry gas volume meter (Shinagawa, DC-5, Tokyo, Japan) and then converted to the volume under conditions of standard temperature, pressure, and dry gas (STPD). The gas exchange results were converted to BMR (kcal/d) using Weir's equation (*22*).

Predictive equations of BMR. Predictive BMR was calculated using the Ganpule (*18*), Japan-DRI (*23*), Harris-Benedict (*24, 25*), Schofield (*26*), Owen (*14, 15*), and Mifflin (*16*) equations (Table 2). The Japan-DRI provided the BMR standards (standard BMR per unit weight) according to age and sex category, with the data for these standards being obtained from a Japanese BMR database (*21, 23*). The Owen and Mifflin equations were developed using data obtained from adults including obese subjects.

Blood samples. Venous blood samples were collected after a fast of at least 12 h for measurement of fasting glucose, glycosylated hemoglobin (HbA_{1c}), insulin, triglycerides, and free fatty acid. The value of the internationally used HbA_{1c} (%) (HbA_{1c} [NGSP]) defined by the NGSP (National Glycohemoglobin Standardization Program), was calculated by adding 0.4% to the obtained HbA_{1c} (JDS) (%) defined by the Japan Diabetes Society (JDS) (*27*). Insulin and free fatty acids were examined using the laboratory testing services provided by SRL Inc. (Tokyo, Japan). Insulin (μIU/mL) was measured using CLEIA (Lumipulse Presto Insulin, Fujirebio Inc.), which has a minimal detection limit of 0.3 μIU/mL. Free fatty acid (mEq/L) was determined using an enzymatic assay (NEFA-SS 'Eiken,' Eiken Chemical Co. Ltd., Tokyo, Japan) with a sensitivity of 0.005 mEq/L. Other blood parameters were analyzed in the clinical laboratory of Saku Central Hospital. HOMA-R was calculated as fasting insulin (μIU/mL)×fasting glucose (mg/dL)/405.

All subjects underwent a 75-g oral glucose tolerance test. The subjects were divided into three groups according to the Diagnosis Criteria Exploratory Committee of the Japan Diabetes Society (2010) (*27*): non-diabetes (n=10), pre-diabetes (n=7), and diabetes (n=13).

Statistical analysis. The results are expressed as the mean±standard deviation (SD). Statistical significance was set at $p<0.05$. The Kolmogorov-Smirnov test was used for statistical testing of normality. HbA_{1c} and fasting insulin were log transformed as the data were not normally distributed. Differences in body composition, blood parameters, and BMR (kcal/d, kcal/kg weight/d and kcal/kg FFM/d) among the three groups were evaluated using one-way analysis of variance (ANOVA) and the Bonferroni post hoc test. Analysis of covariance (ANCOVA) with BMR as the dependent variable and FFM, FM, age, and sex as covariates was carried out. In order to examine the mechanism for differences in BMR, the blood sample measurements such as fasting glucose were added to FFM, FM, age, and sex in ANCOVA. The interaction terms with sex and body composition variables were examined in these analyses. Multiple linear regression models were also constructed using BMR as the dependent variable and FFM, FM, age, and sex as the independent variables. Gender was treated as a binomial variable (0 for male subjects, 1 for female subjects). Body height was not adjusted for, as it did not contribute significantly to BMR in the models ($p>0.05$). The relationships between the residual (measured BMR minus BMR after adjustment for FFM, FM, age, and sex) and fasting glucose, $\log_e HbA_{1c}$, $\log_e$ fasting insulin, HOMA-R, triglycerides, and free fatty acid were examined using Pearson's correlation coefficients. The statistical significance of differences between measured BMR and predicted equation BMR was analyzed by one-way ANOVA with repeated measurements and Dunnett's post hoc test, while differences between predicted and measured BMR values among non-diabetes, pre-diabetes, and diabetes were evaluated by one-way ANOVA and Bonferroni's post hoc test. The statistical analyses were performed using SPSS for Windows (version 18.0; SPSS Inc., Chicago, IL, USA).

RESULTS

No significant difference was observed in body composition among the three groups (Table 1). The subjects with diabetes had significantly higher fasting glucose and $\log_e HbA_{1c}$ levels than subjects with non-diabetes. There was no interaction between sex and diabetes diagnosis in the relationship to BMR (F=2.166, p=0.137). Moreover the interaction terms with sex and body composition variables in ANCOVA with BMR as the dependent variable were not significant. Therefore, both sexes were combined in all analyses. After adjustment for FFM, FM, age, and sex the BMR in subjects with diabetes was 7.1% higher than in non diabetic subjects (Table 3). The ANCOVA showed fasting glucose

Table 3. Basal metabolic rate in subjects with non-diabetes, pre-diabetes, or diabetes.

	Non-diabetes (n=10) Mean±SD	Pre-diabetes (n=7) Mean±SD	Diabetes (n=13) Mean±SD	ANOVA p value	ANCOVA p value
Measured BMR (kcal/d)	1,486±182	1,484±183	1,711±221[a]	0.018	—
(kcal/kg weight/d)	18.3±1.5	18.2±1.4	19.6±1.5	0.054	—
(kcal/kg FFM/d)	27.9±3.3	29.0±4.4	31.2±3.6	0.106	—
Adjusted BMR (FM, FFM, age, sex) (kcal/d)	1,531±98	1,537±95	1,648±98[b]	—	0.021
Adjusted BMR (FM, FFM, age, sex, fasting glucose) (kcal/d)	1,535±128	1,538±99	1,644±132	—	0.171

Measured BMR: measured basal metabolic rate. FFM: fat free mass. Adjusted BMR: analysis of covariance with BMR as the dependent variable and FFM, FM, age, sex, and fasting glucose as covariates was carried out. Differences among the non-diabetes, pre-diabetes, and diabetes groups were evaluated by one-way ANOVA and the Bonferroni post hoc test, [a]$p<0.05$ vs. non-diabetes, and also by ANCOVA and the Bonferroni post hoc test, [b]$p<0.05$ vs. non-diabetes.

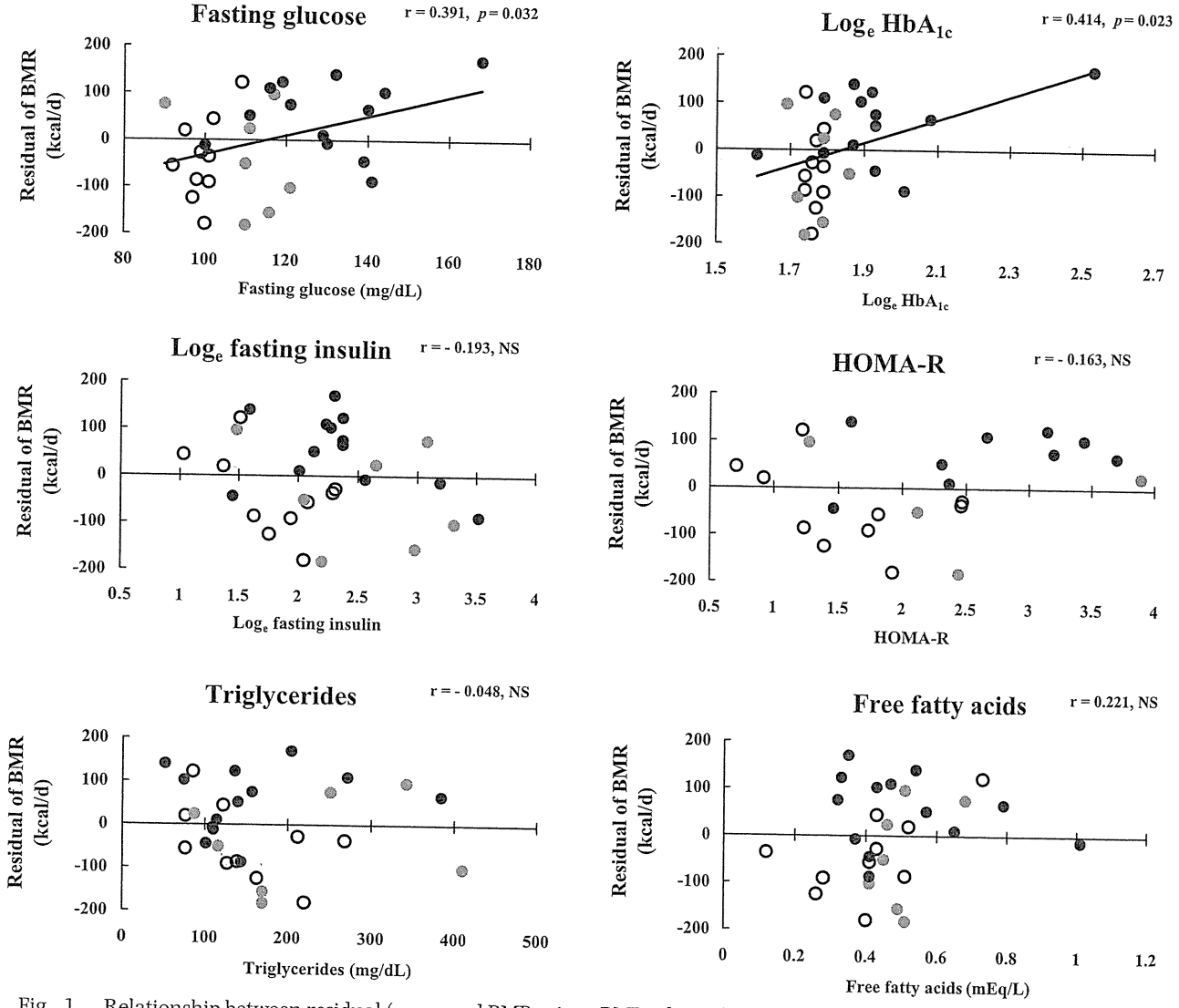

Fig. 1. Relationship between residual (measured BMR minus BMR adjusted for FM, FFM, age, and sex) and fasting glucose, log$_e$ HbA$_{1c}$, log$_e$ fasting insulin, HOMA-R, triglycerides and free fatty acids in subjects without diabetes, pre-diabetes or diabetes. HbA$_{1c}$ and fasting insulin were log transformed. Non-diabetes, white circles (○); pre-diabetes, gray circles (◍); diabetes, black circles (●). The regression lines are for all the subjects.

was an independent determinant of BMR, in addition to FFM, FM, age, and sex. After adjusting for fasting glucose in addition to FFM, FM, age and sex, there were no significant differences in BMR among the three groups. Furthermore, multiple regression analysis demonstrated 81% of the variability (R^2) in BMR was explained by FFM, FM, age, and sex, while fasting glucose as an additional independent variable explained

Table 4. Predicted basal metabolic rate in subjects with non-diabetes, pre-diabetes, or diabetes.

	Mean±SD (kcal/d)	Mean difference±SD (kcal/d)	ANOVA[a] *p* value	Post hoc test[b] *p* value	ANOVA[c] *p* value
Non-diabetes (n=10)			<0.001		
Ganpule	1,511±194	25±119		0.844	0.019[d]
Japan-DRI	1,712±175	227±117		<0.001	0.222
Harris-Benedict	1,584±196	99±127		0.002	0.061
Schofield	1,660±209	175±117		<0.001	0.068
Owen	1,548±219	62±123		0.094	0.075
Mifflin	1,499±209	13±126		0.990	0.026[d]
Pre-diabetes (n=7)			0.001		
Ganpule	1,502±214	17±148		0.977	
Japan-DRI	1,727±241	242±132		<0.001	
Harris-Benedict	1,583±210	98±159		0.111	
Schofield	1,648±222	163±185		0.002	
Owen	1,532±229	48±198		0.734	
Mifflin	1,486±226	2±167		1.000	
Diabetes (n=13)			<0.001		
Ganpule	1,601±237	−110±99		<0.001	
Japan-DRI	1,856±290	146±147		<0.001	
Harris-Benedict	1,692±253	−19±110		0.898	
Schofield	1,766±263	55±98		0.065	
Owen	1,649±264	−62±99		0.032	
Mifflin	1,585±242	−126±100		<0.001	

Mean difference: Mean of difference between predicted and measured BMR. ANOVA[a]: Significance of differences between predicted and measured BMR analyzed by one-way ANOVA with repeated measurements and Dunnett's post hoc test. Post hoc test[b]: Predicted vs. Measured. ANOVA[c]: Differences in predicted equation between non-diabetes, pre-diabetes and diabetes evaluated by one-way ANOVA and Bonferroni post hoc test. [d]$p<0.05$, Bonferroni post hoc test, non-diabetes vs. diabetes.

another 3% of the variability in BMR.

The relationships among residual BMR (measured BMR minus BMR after adjustment for FFM, FM, age, and sex) and fasting glucose, $\log_e$ HbA_{1c}, $\log_e$ fasting insulin, HOMA-R, triglycerides, and free fatty acids are shown in Fig. 1. Residual BMR correlated significantly with fasting glucose (r=0.391, p=0.032) and $\log_e$ HbA_{1c} (r=0.414, p=0.023), although there was no significant correlation between residual BMR and $\log_e$ fasting insulin, HOMA-R, triglycerides, or free fatty acid.

Table 4 shows differences between BMR predicted from six equations and measured BMR in subjects with non-diabetes, pre-diabetes, or diabetes. Predicted BMR values by Ganpule, Owen and Mifflin equations were not significantly different from the measured BMR in non- or pre diabetes. On the other hand, for diabetes there was no significant difference between measured and predicted BMR calculated by Harris-Benedict and Schofield equations. The differences between BMR predicted by Ganpule and Mifflin equations and measured BMR was significant lower in subjects with diabetes than in subjects without diabetes. The prediction error by Ganpule and Mifflin equations were similar to that calculated when BMR was adjusted for FM, FFM, age, and sex (Table 3). For the other equations, no significant differences were found between predicted and measured BMR.

DISCUSSION

This study compared BMRs among subjects with non-diabetes, pre-type 2 diabetes and type 2 diabetes in the obese Japanese population. The results showed that obese Japanese subjects with type 2 diabetes had significantly higher BMR than obese Japanese without diabetes. A similar trend has been demonstrated in previous studies. Furthermore, given the significant relationship we observed between residual BMR and fasting glucose, it is possible that fasting glucose level may be a factor in the higher BMR found in obese subjects with type 2 diabetes.

Several previous studies have examined whether or not BMR in patients with type 2 diabetes is higher than in non-diabetic subjects. Huang et al. (*28*) reported that BMR in these patients was 8.4% higher in females and 4.6% higher in males than in the corresponding non-diabetic subjects. Maiolo et al. (*29*) also reported that BMR was 35% higher in diabetic patients. It is important to note that BMR was not adjusted for body composition in these studies which may explain a large portion of the increase in BMR. On the other hand, two previous studies performed similar comparisons after adjustment for BMR. Fontvieille et al. (*3*) showed in Pima Indians that the BMR in patients with type 2 diabetes (weight: 107±33 kg, body fat: 32±9%) was 5.2% higher than in non-diabetic subjects (weight: 99±24 kg, body fat: 39±7%). Bitz et al. (*4*) also compared BMRs between subjects with or without type 2 diabetes in Caucasians and showed that BMR in the diabetic subjects (BMI: 35.5±3.7 kg/m^2) was 6.9% higher than in non-diabetic subjects (BMI: 34.1±4.7 kg/m^2). In the

present study, BMR adjusted for FFM, FM, age, and sex, was significantly higher in diabetic compared with non-diabetic subjects (7.1%) (Table 3). Surprisingly, the adjusted BMR in patients with diabetes was higher than in non-diabetic subjects. These three studies using adjusted BMR obtained similar results in different ethnicities.

Although the physiological mechanisms responsible for the increased BMR in individuals with type 2 diabetes are poorly understood, several mechanisms have been proposed to explain this increase. These include increased energy costs during hyperglycaemia, for example gluconeogenesis, protein turnover, and sympathetic nervous system activity (*3*). Bitz et al. (*4*) reported that free fatty acids may be a potential mediator in several mechanisms associated with increased BMR. Gougeon et al. (*30*) reported that BMR adjusted for weight, FFM, age, and sex was significantly higher in subjects with type 2 diabetes with a fasting plasma glucose >180 mg/dL than those with a level <180 mg/dL (*30*). They used a fasting plasma glucose level of 180 mg/dL as it represents the concentration considered to be the glycosuria threshold which reflects poor control. Gougeon et al. (*30*) also reported that fasting plasma glucose was a significant independent variable and increased the prediction of BMR by more than 3%. In the present study, we showed a significant relationship between residual BMR and fasting glucose (Fig. 1). After adjusting for fasting glucose in addition to FFM, FM, age and sex, there were no significant differences in BMR among the three groups (Table 3). Fasting glucose as an additional independent variable explained another 3% of the variability in BMR by multiple regression analysis. Therefore, the degree to which fasting glucose contributes to BMR was similar in different ethnicities. Weyer et al. (*31*) reported that a higher endogenous glucose output (EGO) was a relatively late finding in the development of type 2 diabetes and typically was not evident until the transition from impaired glucose tolerance (IGT) to diabetes. The extent to which the energy cost of EGO contributes to increased BMR is, therefore, probably less in individuals with IGT than in those with diabetes. In the present study, BMR in pre-diabetic subjects was not significantly higher than that measured in non-diabetic subjects. Fasting glucose values were also similar in non-diabetic and pre-diabetic subjects, which may have contributed to the similar BMR values we observed between the two groups. This result supports the results of Weyer et al. (*31*). In summary, higher BMR in obese subjects with type 2 diabetes may be related to fasting glucose level.

One of the limitations of the present study is the relatively small sample size. In the present study, both sexes were combined. Moreover, one diabetic patient who received metformin or glibenclamide therapy and another diabetic patient who had experienced diabetes patient education program in the past were included. However, more detailed analyses with larger samples size are needed for the better understanding of the effects of sex and medication. In panticular, there is some possibility that medication affects the relationship between blood glucose and BMR through the suppression of blood fasting glucose.

As the majority of clinical facilities do not have indirect calorimetry, BMR is usually estimated from predictive equations using data such as age, sex, height, and weight (*11*). A predictive equation of BMR in obese subjects is important to provide the basis for an individualized treatment plan for weight loss (*28*). In the present study, we examined the validity of six predictive equations for BMR in Japanese subjects with non-diabetes, pre-diabetes or diabetes. The Ganpule (*18*) and Japan-DRI (*21, 23*) equations were developed based on data from Japanese subjects. The Harris-Benedict (*24, 25*), Schofield (*26*), Owen (*14, 15*), and Mifflin (*16*) equations are used internationally. The Harris-Benedict equation is the most common method for calculating BMR (*26*), while the Owen (*14, 15*) and Mifflin (*16*) equations were developed in adults including obese subjects.

Huang et al. (*28*) demonstrated that the Harris-Benedict equation overestimated BMR in diabetic males and underestimated the value in diabetic females, while Gougeon et al. (*30*) reported that BMR predicted by the Owen equations did not differ significantly from measured BMR in obese diabetic males. In the present study, the differences between BMR predicted by Ganpule and Mifflin equations and measured BMR was significant lower and negative for most predictive equations in subjects with diabetes than in subjects without diabetes. In the present study, ANCOVA showed that the differences in average prediction error of the Ganpule and Mifflin equation among the three groups were comparable to the differences obtained after adjustment for FM, FFM, age, and sex. BMR was underestimated by 110 and 126 kcal/d in diabetes, while predicted BMR was comparable to measured BMR in the non-diabetes and pre-diabetes groups. Therefore, adjustment should be made for diabetes when predicting BMR.

In conclusion, obese Japanese with type 2 diabetes have higher BMR than obese Japanese without diabetes. This phenomenon appears to be similar in different ethnicities such as Pima Indians, Caucasians, and Asians. Although the physiological mechanisms responsible for the increased BMR in subjects with type 2 diabetes remain unclear, the fasting glucose level could be a major factor contributing to this increase. Furthermore, the difference between the prediction errors of the Ganpule and Mifflin equation in subjects with and without diabetes tended to be significant and was comparable to those when BMR was adjusted for FM, FFM, age, and sex. It is therefore important to pay attention to the prediction error for BMR in diabetic patients in the clinical setting.

Acknowledgments

We express our heartfelt thanks to the subjects who participated in the present study. We thank the members of Saku Control Obesity Program, especially Ms Hiroko Kogure, Mr Takafumi Ando, and Ms Emiko

Taguri, for their help in data acquisition and analysis. This study was supported by Health and Sciences Research Grants for Comprehensive Research on Cardiovascular and Life-Style Related Diseases from the Japanese Ministry of Health, Labour and Welfare (PI: S.W. and PI: S.T.).

REFERENCES

1) Ministry of Health, Labour and Welfare of Japan. 2010. The National Health and Nutrition Survey in Japan, 2007. Daiichi Shuppan, Tokyo (in Japanese).
2) Parillo M, Riccardi G. 2004. Diet composition and the risk of type 2 diabetes: epidemiological and clinical evidence. *Br J Nutr* **92**: 7–19.
3) Fontvieille AM, Lillioja S, Ferraro RT, Schulz LO, Rising R, Ravussin E. 1992. Twenty-four-hour energy expenditure in Pima Indians with Type 2 (non-insulin-dependent) diabetes mellitus. *Diabetologia* **35**: 753–759.
4) Bitz C, Toubro S, Larsen TM, Harder H, Rennie KL, Jebb SA, Astrup A. 2004. Increased 24-h energy expenditure in type 2 diabetes. *Diabetes Care* **27**: 2416–2421.
5) Payne PR, Waterlow JC. 1971. Relative requirements for maintenance, growth and physical activity. *Lancet* **2**: 210–211.
6) Efendic S, Wajngot A, Vranic M. 1983. Hepatic futile cycle is an important metabolic pathway in lean type 2 diabetics. *Diabetes* **32** (Suppl 1): 282 (abstract).
7) Felig P, Wahren J, Hendler R. 1978. Influence of maturity-onset diabetes on splanchnic glucose balance after oral glucose ingestion. *Diabetes* **27**: 121–126.
8) Davidson IWF, Salter JM, Best CH. 1960. The effect of glucagon on the metabolic rates of rats. *Am J Clin Nutr* **8**: 540–545.
9) Shai I, Jiang R, Manson JE, Stampfer MJ, Willett WC, Colditz GA, Hu FB. 2006. Ethnicity, obesity, and risk of type 2 diabetes in women: a 20-year follow-up study. *Diabetes Care* **29**: 1585–1590.
10) Fukushima M, Usami M, Ikeda M, Nakai Y, Taniguchi A, Matsuura T, Suzuki H, Kurose T, Yamada Y, Seino Y. 2004. Insulin secretion and insulin sensitivity at different stages of glucose tolerance: a cross-sectional study of Japanese type 2 diabetes. *Metabolism* **53**: 831–835.
11) Leung R, Woo J, Chan D, Tang N. 2000. Validation of prediction equations for basal metabolic rate in Chinese subjects. *Eur J Clin Nutr* **54**: 551–554.
12) Case KO, Brahler CJ, Heiss C. 1997. Resting energy expenditures in Asian women measured by indirect calorimetry are lower than expenditures calculated from prediction equations. *J Am Diet Assoc* **97**: 1288–1292.
13) Daly JM, Heymsfield SB, Head CA, Harvey LP, Nixon DW, Katzeff H, Grossman GD. 1985. Human energy requirements: overestimation by widely used prediction equation. *Am J Clin Nutr* **42**: 1170–1174.
14) Owen OE, Kavle E, Owen RS, Polansky M, Caprio S, Mozzoli MA, Kendrick ZV, Bushman MC, Boden G. 1986. A reappraisal of the caloric requirements in healthy woman. *Am J Clin Nutr* **44**: 1–19.
15) Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, Kavle EC, Bushman MC, Owen LR, Mozzoli MA, Kendrick ZV, Boden GH. 1987. A reappraisal of the caloric requirements of man. *Am J Clin Nutr* **46**: 875–885.
16) Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. 1990. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr* **51**: 241–247.
17) Henry CJK, Rees DG. 1991. New predictive equations for the estimation of basal metabolic rate in tropical peoples. *Eur J Clin Nutr* **45**: 177–185.
18) Ganpule AA, Tanaka S, Ishikawa-Takata K, Tabata I. 2007. Interindividual variability in sleeping metabolic rate in Japanese subjects. *Eur J Clin Nutr* **61**: 1256–1261.
19) Miyake R, Tanaka S, Ohkawara K, Ishikawa-Takata K, Hikihara Y, Taguri E, Kayashita J, Tabata I. 2011. Validity of predictive equations for basal metabolic rate in Japanese adults. *J Nutr Sci Vitaminol* **57**: 224–232.
20) Morita A, Ohmori Y, Suzuki N, Ide N, Morioka M, Aiba N, Sasaki S, Miyachi M, Noda M, Watanabe S, for SCOP Group. 2008. Anthropometric and clinical findings in obese Japanese: The Saku Control Obesity Program (SCOP). *Anti-Aging Med* **5**: 13–16.
21) Yamamoto S, Komatsu T. 2001. Evaluation of the data on basal metabolic rate for Japanese. *Jpn J Nutr Diet* **59**: 51–59 (in Japanese).
22) Weir JB. 1949. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* **109**: 1–9.
23) Ministry of Health, Labour and Welfare of Japan. 2009. Dietary Reference Intakes for Japanese, 2010. Daiichi Shuppan, Tokyo (in Japanese).
24) Harris JA, Benedict FG. 1919. A Biometric Study of Basal Metabolism in Man. Carnegie Institute of Washington, Washington DC.
25) Frankenfield DC, Muth ER, Rowe WA. 1998. The Harris-Benedict studies of human basal metabolic: History and limitations. *J Am Diet Assoc* **98**: 439–445.
26) Schofield WN. 1985. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* **39C**: 5–41.
27) Seino Y, Nanjo K, Tajima N, Kadowaki T, Kashiwagi T, Araki E, Ito C, Inagaki N, Iwamoto Y, Kasuga M, Hanafusa T, Haneda M, Ueki K. 2010. Report of the Committee on the classification and diagnostic criteria of diabetes mellitus: The Committee of the Japan Diabetes Society on the diagnostic criteria of diabetes mellitus. *Diabetol Int* **1**: 2–20.
28) Huang KC, Kormas N, Steinbeck K, Loughnan G, Caterson ID. 2004. Resting metabolic rate in severely obese diabetic and nondiabetic subjects. *Obes Res* **12**: 840–845.
29) Maiolo C, Mohamed EI, Servidio MF, De Luna A, Meloni P, Bertoli A, De Lorenzo A. 2003. The effect of physical activities of various intensities on the energy expenditure of type 2 diabetic men. *Acta Diabetol* **40**: S126–S129.
30) Gougeon R, Lamarche M, Yale JF, Venuta T. 2002. The prediction of resting energy expenditure in type 2 diabetes mellitus is improved by factoring for glycemia. *Int J Obes Relat Metab Disord* **26**: 1547–1552.
31) Weyer C, Bogardus C, Pratley RE. 1999. Metabolic factors contributing to increased resting metabolic rate and decreased insulin-induced thermogenesis during the development of type 2 diabetes. *Diabetes* **48**: 1607–1614.

Tudor-Locke et al. International Journal of Behavioral Nutrition and Physical Activity 2011, 8:78
http://www.ijbnpa.org/content/8/1/78

INTERNATIONAL JOURNAL OF BEHAVIORAL NUTRITION AND PHYSICAL ACTIVITY

REVIEW Open Access

How Many Steps/Day are Enough? for Children and Adolescents

Catrine Tudor-Locke[1,2*], Cora L Craig[2,3], Michael W Beets[4], Sarahjane Belton[5], Greet M Cardon[6], Scott Duncan[7], Yoshiro Hatano[8], David R Lubans[9], Timothy S Olds[10], Anders Raustorp[11,12], David A Rowe[13], John C Spence[14], Shigeho Tanaka[15] and Steven N Blair[16]

Abstract

Worldwide, public health physical activity guidelines include special emphasis on populations of children (typically 6-11 years) and adolescents (typically 12-19 years). Existing guidelines are commonly expressed in terms of frequency, time, and intensity of behaviour. However, the simple step output from both accelerometers and pedometers is gaining increased credibility in research and practice as a reasonable approximation of daily ambulatory physical activity volume. Therefore, the purpose of this article is to review existing child and adolescent objectively monitored step-defined physical activity literature to provide researchers, practitioners, and lay people who use accelerometers and pedometers with evidence-based translations of these public health guidelines in terms of steps/day. In terms of normative data (i.e., expected values), the updated international literature indicates that we can expect 1) among children, boys to average 12,000 to 16,000 steps/day and girls to average 10,000 to 13,000 steps/day; and, 2) adolescents to steadily decrease steps/day until approximately 8,000-9,000 steps/day are observed in 18-year olds. Controlled studies of cadence show that continuous MVPA walking produces 3,300-3,500 steps in 30 minutes or 6,600-7,000 steps in 60 minutes in 10-15 year olds. Limited evidence suggests that a total daily physical activity volume of 10,000-14,000 steps/day is associated with 60-100 minutes of MVPA in preschool children (approximately 4-6 years of age). Across studies, 60 minutes of MVPA in primary/elementary school children appears to be achieved, on average, within a total volume of 13,000 to 15,000 steps/day in boys and 11,000 to 12,000 steps/day in girls. For adolescents (both boys and girls), 10,000 to 11,700 may be associated with 60 minutes of MVPA. Translations of time- and intensity-based guidelines may be higher than existing normative data (e.g., in adolescents) and therefore will be more difficult to achieve (but not impossible nor contraindicated). Recommendations are preliminary and further research is needed to confirm and extend values for measured cadences, associated speeds, and MET values in young people; continue to accumulate normative data (expected values) for both steps/day and MVPA across ages and populations; and, conduct longitudinal and intervention studies in children and adolescents required to inform the shape of step-defined physical activity dose-response curves associated with various health parameters.

Background

The profound and robust benefits of a physically active lifestyle are recognized even for young people. Hence, worldwide, public health physical activity guidelines include special emphasis on children (typically 6-11 years) and adolescents (typically 12-19 years) [1-3], and there is growing interest in providing guidelines for preschool children [4]. Existing guidelines are commonly expressed in terms of frequency, time, and intensity of behaviour. However, with the technological advancement of objective monitoring of physical activity using pedometers and accelerometers, the opportunity now exists to offer another type of message that is congruent with these established guidelines. Although accelerometers offer a greater potential to study complex patterns of physical activity and sedentary behaviours in the course of research, the simple step output from both accelerometers and

* Correspondence: Tudor-Locke@pbrc.edu
[1]Walking Behavior Laboratory, Pennington Biomedical Research Center, Baton Rouge, LA, USA
Full list of author information is available at the end of the article

pedometers is gaining increased credibility in both research and practice as a reasonable approximation of daily ambulatory physical activity volume [5,6]. Of the two types of instrumentation, pedometers are more likely to be adopted for clinical and public health applications, and ultimately are also more likely to be embraced by the public themselves, due primarily to interpretability and relative low cost. Such users (i.e., clinicians, public health practitioners, and the general public) require good reference data and recommendations that are grounded in evidence in order to facilitate an effective step-based translation of public health guidelines. The purpose of this manuscript is to convey findings that inform a translation of public health guidelines for children and adolescents in terms of steps/day.

Methods

This literature review was commissioned by the Public Health Agency of Canada (PHAC) and includes: 1) normative data (i.e., expected values); 2) incremental changes expected from interventions; 3) controlled studies translating cadence (i.e., steps/minute) to activity intensity; 4) studies of steps/day associated with time in moderate-to-vigorous physical activity (MVPA) under free-living conditions; and, 5) health outcome-related analyses (e.g., steps/day associated with valued health outcomes). In February 2010 a professional librarian executed the search strategy of CINAHL, ERIC, MEDLINE, PsycINFO, SocINDEX, and SPORTDiscus using the keywords (pedomet* or acceleromet*) and step* and ((physical activity) or walk*), limited to English language, and published since 2000 (an earlier review covered studies published before 2000 [7]). Articles were assembled, additional research was identified by reviewing article reference sections, and relevant content was abstracted and summarized by the first author. Where recent review articles were identified (e.g., normative data, interventions), the summarized results were presented to avoid redundancy and notable original articles selected to make specific points. Subsequently, researchers with practical experience collecting step data worldwide were invited to critically review the report, identify any additional relevant literature (including known articles in press), and intellectually contribute to this consensus document focused on children and adolescents. Study details were tabulated as appropriate. Any seeming inconsistencies in details catalogued within tables (e.g., instrument brand, model, numbers of decimal points, etc.) reflect underlying reporting inconsistencies as taken directly from original articles. The adult [8] and older adult/special populations [9] literature is reviewed separately.

Results

Normative data (expected values)

Normative steps/day data (or expected values) provide an indication of central tendency and variability and are useful for comparison purposes and interpreting change. However, they should not imply what children or adolescents "should" be taking, an index more appropriately described as a cut point or threshold value. Early work [7] that attempted to collate normative data (from studies published between 1980 and 2000) reported, based on a single study [10] published at the time, that we can expect 8-10 year old children to take 12,000 to 16,000 steps/day (lower for girls than boys). No data were available at the time to inform the number of steps/day that adolescents take. Since then, however, studies of young people's step data collected using pedometers and accelerometers have proliferated. In particular, two reviews have published normative data for children, together covering each sex-age group from 5-19 years of age [11,12]. Among children, boys average 12,000 to 16,000 steps/day and girls average 10,000 to 13,000 steps/day [11]. Although there are exceptions among countries, in general, peak values of mean steps/day occur before 12 years of age and decrease through adolescence until mean values of approximately 8,000 and 9,000 steps/day are observed in 18-year olds [12]. Across studies, physical education class participation generally contributes ≅9-24% of daily steps in boys and ≅11.4-17.2% in girls, and afterschool activity accounts for ≅47-56% and ≅47-59% (boys and girls respectively) of daily steps on school days [11]. Differences among countries are apparent, with children from North America (Canada and United States) showing lower values compared to other regions of the world, for example, when compared to European countries (Sweden, United Kingdom, Belgium, Czech Republic, France, Greece, and Switzerland), but especially when compared to Western Pacific countries (Australia and New Zealand) [12].

Beyond these reviews, a few specific references relative to normative data in young people are noteworthy. Vincent and Pangrazi [13] reported normative data for a U. S. sample in 2002 and at that time suggested that the mean values of 13,000 for U.S boys and 11,000 for U.S. girls could be used as reasonable standards for evaluation purposes. The U.S. President's Challenge: Physical Activity and Fitness Awards Program [14] adopted these same values to recognize physically active U.S. children (ages 6-17 years). A number of researchers from around the world have used these same values as cut points to evaluate data [15-17] although they can only be traced back to mean values based on a single descriptive study [13] of weekday step values obtained by 711 children aged 6-12 years living in the Southwestern U.S. The

National Health and Nutrition Examination Survey (NHANES) in the U.S. adopted an accelerometer to objectively monitor physical activity in the 2003-2004 and 2005-2006 cycles; step data for children and adolescents collected in 2005-2006 have been recently published [5]. Once adjusted (i.e., reduced to those steps taken above a specified intensity) to make these accelerometer-determined step data interpretable against common pedometer-based scales, the results indicate that American young people aged 6-19 years take approximately 9,500 (boys) and 7,900 (girls) steps/day [5]. The 2005-2007 Canadian Physical Activity Levels Among Youth (CANPLAY) pedometer-determined physical activity data (based on a nationally representative sample of > 11,500 Canadian young people) are also just recently available [6,18]. The results indicate that Canadian young people aged 5-19 years of age take 12,000 (boys) and 11,000 (girls) steps/day [6]. To put these American and Canadian values in context, Amish young people 6-18 years of age, who purposefully refrain from adopting most technologies of modern living, average over 15,000 steps/day [19].

Tudor-Locke and Bassett [20] established pedometer-determined physical activity cut points for healthy adults: 1) < 5,000 steps/day (sedentary); 2) 5,000-7,499 steps/day (low active); 3) 7,500-9,999 steps/day (somewhat active); 4) ≥ 10,000-12,499 steps/day (active); and 5) ≥12,500 steps/day (highly active). These categories were reinforced in an updated review in 2008 [21] and in 2009 the original sedentary level was segmented into two additional levels: < 2,500 steps/day (basal activity) and 2,500 to 4,999 steps/day (limited activity) [22]. A similar (but sex-specific) graduated step index has been introduced for children (ages 6-12 years) [21]. Values for boys are: 1) < 10,000; 2) 10,000-12,499; 3) 12,500-14,999; 4) 15,000 - 17,499; and, 5) ≥ 17,500 steps/day. The corresponding values for girls are: 1) < 7,000; 2) 7,000-9,499; 3) 9,500-11,999; 4) 12,000 - 14,499 and, 5) ≥ 14,500 steps/day. The primary anchors for both of these sex-specific indices were based on a BMI-referenced criterion study of U.S., Australian, and Swedish children 6-12 years of age [23], and the appropriateness and generalizability of these cut points have been questioned [24]. The increments in the children's graduated step index were selected to be congruent with the adult index. For both sexes, each escalating category can be interpreted as "sedentary", "low active," "somewhat active," "active," and "highly active" similar to the labels used to define levels in the adult graduated step index, however, they have also been given labels of "copper," "bronze," "silver," "gold", and "platinum," in keeping with a style reflective of current physical activity and fitness award programs in the U.S. [14]. Another strategy might be to adopt existing graduated Canadian Physical Activity, Fitness and Lifestyle Approach (CPAFLA) [25] labels: Needs Improvement, Fair, Good, Very Good, and Excellent. It may be difficult to avoid unintentional potential for stigmatization using any qualitative label, however [21]. Only a single study has used this index to describe distribution of child data at this time [5] and we know of no validation study with regards to any other health parameter. An additional criticism of this version of children's graduated index could be that there are not enough "rungs on the ladder" leading up to the identified floor values separating 'sedentary' from 'low active." As indicated above, two additional levels have been added to the adult version. There is very little step data to inform an adolescent-specific graduated step index at this time.

Seventeen studies were identified that have reported relative achievement of various step-defined cut points and these are presented in Table 1 by publication year. Three of these have used the Vincent and Pangrazi [13] and/or President's Active Lifestyle Award [14] values of 13,000 for boys and 11,000 for girls (based on normative values for American adolescents [13]). Six have used BMI-referenced values (15,000 for boys, 12,000 for girls) described above [23]. Four have examined both of these, one used the Rowlands and Eston [16] cut points of 13,000 (boys) and 12,000 (girls) based on accumulating > 60 minutes in accelerometer-determined MVPA within the course of daily activity, one used the sex-specific children's graduated step index [23], and the remainder have used other variations. In general, 1) relatively more children than adolescents achieve a given cut point, 2) relatively more children and adolescents are able to achieve lower (rather than higher) cut points, and 3) relatively fewer U.S. children and adolescents achieve the same cut points when compared to those from other countries. Not included in the table is a study by Beets et al. [24] which evaluated the BMI-referenced cut points (e.g., in terms of sensitivity and specificity) but did not report the actual percentage of the sample achieving them.

In summary, the updated normative data (i.e., expected values) based on international studies indicates that we can expect 1) among children, boys to average 12,000 to 16,000 steps/day and girls to average 10,000 to 13,000 steps/day; and, 2) steps/day values in adolescents to steadily decrease until approximately 8,000-9,000 steps/day are observed in 18-year olds.

Interventions

A systematic review of studies that have used pedometers to promote physical activity in children and adolescents has been recently published [26]. Only 14 studies were identified, and 12 of these documented increases in physical activity. The magnitude of the

Table 1 Studies reporting percent meeting select step-defined cut points in young people

Reference	Sample Characteristics	Instrument	Monitoring Frame	Cut points Used	% Meeting Specified Cut point
Raustorp [59] 2003 Sweden	446 boys, 457 girls; school children; 6-14 years	Yamax Digiwalker SW-200 (Tokyo, Japan)	4 weekdays	VP/PALA	83% boys, 82% girls
Cardon [15] 2004 Belgium	51 boys, 41 girls; elementary school children; 6.5-12.7 years	Yamax Digiwalker SW-200, Yamax Corp, Japan	7 days	VP/PALA BMI-referenced cut points	77% overall 63% overall
Rowlands [16] 2005 UK	13 boys, 13 girls; primary school children; 8 to 10 years	Yamax Digi-Walker DW-200, Yamasa, Tokyo, Japan	6 days including 1 weekend day	VP/PALA BMI-referenced cut points	62% boys, 69% girls 38% boys, 54% girls
Parfitt [60] 2005 UK	35 boys, 25 girls; primary school children; 9.8 to 11.4 years	Yamax Digiwalker SW-200, Yamasa, Tokyo, Japan	7 days	Rowlands and Eston 13000, 12000	25% boys, 30% girls
Zizzi [61] 2006 USA	56 boys, 109 girls; high school students; 14 to 17 years	Accusplit Eagle 170	7 days	VP/PALA	< 25% overall
Raustorp [62] 2007 Sweden	183 boys in 2000 85 boys in 2006 153 girls in 2000 83 girls in 2006; School children; 7 to 9 years	Yamax SW-200 Tokyo, Japan	4 weekdays	BMI-referenced cut points	2000: 67% boys, 90% girls 2006: 60% boys, 75% girls
Duncan [63] 2007 UK	101 boys, 107 girls; primary school children; 8 to 11 years	New Lifestyles, NL2000, Montana, USA	4 days including 2 weekend days	BMI-referenced cut points	28.7% boys, 46.7% girls 41.2% of normal weight, 36.4% of overweight, 12.5% of obese
Eisenmann [57] 2007 USA	269 boys, 339 girls; Midwestern elementary school children; 9.6 years	Digiwalker 200 SW	7 days	VP/PALA	not reported
				BMI-referenced cut points	not reported
				< 10000	19.3% boys, 33.9% girls
				10000-12000	24.2% boys, 32.4% girls
				12000-14000	24.2% boys, 22.7% girls
				> 14000	32.3% boys, 10.9% girls
Raustorp [64] 2007 Sweden	46 boys, 51 girls; School children; 12-14 years	Yamax SW-200	4 weekdays	BMI-referenced cut points	58% overall
Reed [65] USA 2007	140 boys, 158 girls; elementary school children; 6 to 10 years	New Lifestyles Digi-Walker, SW-401, Yamax, Inc.	7 days	VP/PALA	41% overall
				Grade	Boys Girls
				First	35.70% 17.20%

Table 1 Studies reporting percent meeting select step-defined cut points in young people *(Continued)*

				Second	55.00% 18.20%
				Third	78.60% 44.80%
				Fourth	48.10% 50.00%
				Fifth	51.40% 12.90%
Downs [66] Canada 2008	80 boys, 98 girls; Cree elementary school children; 9 to 11 years	Yamax SW-200 Digiwalker, Yamasa Corp., Tokyo, Japan	3 weekdays	BMI-referenced cut points	59% overall, 51% with central adiposity, 68% without
Hohepa [67] 2008 New Zealand	95 boys, 141 girls; high school students; 12 to 18 years	NL-2000 New-Lifestyles Inc.	7 days	10,000	11.4% never met 24.4% sometimes met 49.7% often met 14.5% always met
Laurson [55] 2008 USA	358 boys, 454 girls; elementary school children; 6 to 12 years	Digiwalker 200-SW	7 days	VP/PALA	41.3% boys, 45.6% girls
				BMI-referenced cut points	23.2% boys, 31.5% girls
				adult 10,000	80.2% boys, 63.2% girls
				11,500 and 10,000 (boys, girls)	62.6% boys, 63.2% girls
				10,000 and 11,000	80.2% boys, 45.6% girls
Lubans [17] 2008 Australia	50 boys, 65 girls; adolescents recruited through schools; 14.15 ± 0.76 years	Yamax SW701	5 days including 1 weekend day	VP/PALA BMI-referenced cut points	49% boys, 52% girls 30% boys and girls
Belton [68] 2009 Ireland	153 boys, 148 girls; primary school children; 6 to 9 years	Yamax Digwalker SW200	7 days	BMI-referenced cut points	62.2% boys, 74.7% girls
Craig [6] 2010 Canada	5863 boys, 5639 girls; nationally representative sample 5-19 years	Yamax SW-200 (Tokyo, Japan)	7 days	BMI-referenced cut points 15,000 step/day 16,500 steps/day	23.2% male, 33.8% girls 23.2 male, 11.7% girls 13.8% male, 6.1% girls
Tudor-Locke [5] 2010 USA	1281 boys, 1329 girls, nationally representative sample; 6-19 years	ActiGraph AM-7164, ActiGraph, Ft. Walton Beach, Florida (data treated to approximate pedometer output)	7 days	Sex-specific Children's Graduated Step Index (only in 6-11 year olds)	41.8% boys sedentary 21.2% girls sedentary (other categories presented in figures)

Vincent and Pangrazi U.S. normative data [13] /President's Active Lifestyle Award (VP/PALA) [14]: 13,000 steps/day (boys) and 11000 steps/day (girls). BMI-referenced cut points [23]: 15,000 steps/day (boys) and 12,000 steps/day (girls). Sex-specific Children's Graduated Step Index for children (ages 6-12 years) [21]. Boys: 1) < 10,000; 2) 10,000-12,499; 3) 12,500-14,000; 4) 15,000 - 17,499; and, 5) ≥ 17,500 steps/day. Girls: 1) < 7,000; 2) 7,000-9,499; 3) 9,500-11,999; 4) 12,000 - 14,999 and, 5) ≥ 14,500 steps/day. For both sexes, each escalating category is respectively labelled "sedentary," "low active," "somewhat active," "active," and "highly active."

intervention effects was variable and could very well reflect differences in study participants (e.g., children vs. adolescents, obese vs. non-obese), program factors, study design (e.g., 1-week to 6-month interventions), and/or assessment protocols. Limited evidence suggests that the intervention effects are greater in participants who are 'low active' to begin with. In particular, adolescents who already take ≥13,000-15,000 steps/day do not appear to respond to goal-setting or activity monitoring strategies using pedometers. The magnitude or pattern of change that can be expected from pedometer-based interventions in children and adolescents is not known at this time. The authors of that review concluded that since there were so few intervention studies published, yet the results were generally positive, continued research should be encouraged to inform guidelines with regards to using pedometers to promote physical activity in children and adolescents. It is clear that this area of knowledge is lacking, especially when compared with what is known about pedometer-based interventions in adults [27-29].

Controlled studies

Cadence is the expression of steps taken per unit time (i.e., steps/minute) and it can be used to infer intensity of continuous ambulation [30,31]. Four controlled studies have been conducted with healthy young people [32-35]. The series of studies conducted by Scruggs and colleagues [36-41] were not considered here since they focus on steps detected specifically during physical education classes, which would logically include at least some sedentary time (e.g., for instruction, class management, etc.), and this would effectively lower mean cadence values. In a similar manner, a study by Beets et al. [42] focused on steps associated with time in MVPA detected during afterschool programs was not considered here.

Jago et al. [35] studied pedometer-determined steps taken by 78 11-15 year old USA-based Boy Scouts at externally-paced slow (10 minutes at 4.83 km/hr ≅ 3 METs or moderate intensity) and fast walks (10 minutes at 6.44 km/hr ≅ 5.0 METs or moderate-vigorous intensity) and running (5 minutes at 8 km/hr ≅ 8 METs or vigorous intensity) on a 200 m track. METs (metabolic equivalents) are often used to quantify physical activity intensity with respect to resting or basal metabolic rate (1 MET ≅ 3.5 ml O_2/kg/min or 1 kcal/kg/min for adults). In the Jago et al. [35] study MET level was not directly measured but rather was inferred from the Compendium of Physical Activities [43]. Although participants also wore a CSA accelerometer (an earlier version of the ActiGraph accelerometers) during these trials, the output of that instrument was only used to assess pedometer (New Lifestyles Digiwalker SW-200) validity by correlation and was not otherwise used to inform "how many steps are enough?" Mean steps/minute overall for the slow and fast walks and the run were 117, 127, and 163, respectively. The authors focused on the results of the fast walk (taken at 5 METs) to extrapolate that approximately 4,000 steps in 30 minutes or 8,000 steps in 60 minutes was equivalent to adolescent-appropriate amounts of time in MVPA. However, if 3 METs is considered the floor of moderate intensity activity [44], it follows that 3,510 steps in 30 minutes or 7,020 steps in 60 minutes would be a more literal translation of the results of the slow 3 MET walk. It must be noted, that moderate intensity might be more correctly considered to be 4 METs in children [45]. Since cadences were only measured for 3 MET (slow) and 5 MET (fast) walks, 122 steps/min is a mid-way estimate for a 4 MET walk. This produces an estimate of 3,660 steps in 30 minutes and 7,320 steps in 60 minutes. Since Jago et al. [35] also reported that adolescents at risk of overweight (BMI > 85th percentile) took somewhat fewer steps/minute (i.e., 111, 123, and 156 steps/min for each of the trials), 111 steps/min is the cadence associated with 3 METS and 117 steps/min would be the cadence associated with 4 METs. Together, the floor of moderate intensity might be better captured by a range of approximately 3,300-3,500 steps in 30 minutes (or 6,600-7,000 steps in 60 minutes) of continuous walking at 3 METs or approximately 3,500-3,700 steps in 30 minutes (or 7,000-7,400 steps in 60 minutes) at 4 METs.

Graser et al. [33] asked 34 girls and 43 boys aged 10-12 years to wear a pedometer and walk on a treadmill at 3, 3.5, and 4 miles/hour. Intensity was not directly measured; however, the authors considered these speeds to represent a range of MVPA walking intensities. The boys' and girls' cadence values were similar across the walking speeds and the researchers concluded that, in general, 120-140 steps/minute represented a reasonable cadence range associated with MVPA. Intensity-related translations based on taking 120 steps/minute at 3 miles/hour correspond to 3,600 steps in 30 minutes, or 7,200 steps in 60 minutes. Graser et al. [33] studied a somewhat younger age group than the Jago et al. [35] study and this might have produced relatively higher cadence ranges. Taken together, the two studies indicate that continuous MVPA walking (assuming at least 3 METs) produces 3,300-3,600 steps in 30 minutes or 6,600-7,200 steps in 60 minutes in 10 - 15 year olds. It is important to emphasize that such a translation should only be applied to continuous ambulation performed over the specified amounts of time. It is most important to emphasize that definitions of MVPA differed between these two studies and neither used a direct measure of intensity.