value from biopsy sampled is quite intriguing. However, several limitations should be applicable. First of all, substantial influences of circulation on concentration of metabolites in skeletal muscle should be considered. As we reported (3), difference in lactate concentration in skeletal muscle after 2–3 min of high-intensity exhaustive exercise from resting value is ~30 mmol/kg wet muscle, while muscle glycogen degradation is ~25 mmol glucosyl units/kg wet muscle (6), suggesting that two-fifths of produced lactate is removed from skeletal muscle by circulation during the exercise. Therefore, 1:1 ratio of lactate and $H^+$ observed in the study (2) is only relevant to anoxic condition without blood stream. Furthermore, since during such exercise, aerobic metabolism dominantly releases ATP (~60–70% of total ATP supply), an important simulation hypothesis of Marcinek et al. (2) that oxidation process does not work is not applicable to the high-intensity exhaustive exercise. Oxidation state may affect glycolysis by changing NADH and/or ATP concentrations, which may affect enzyme activity of rate limiting enzyme (presumably PFK) of glycolysis. Future research using NMR with conventional biochemical analyses should be conducted for the purpose of elucidating fatigue during high-intensity exercise.

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# Association between Muscular Strength and Metabolic Risk in Japanese Women, but Not in Men

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**Abstract** We examined whether cardiorespiratory fitness (maximal oxygen uptake, $\dot{V}O_2max$) and muscular strength (grip strength) are associated with individual and clustered metabolic risk factors independently of abdominal adiposity in Japanese men (n=110) and women (n=110) aged 20–69 years. Blood pressure, triglycerides (TG), HDL cholesterol, and fasting plasma glucose (FPG) were assessed and metabolic risk score was calculated, which is the sum of the z scores for each individual risk factor. Waist circumference was measured and the area of visceral fat was assessed by MRI. Multiple linear regression analysis revealed that $\dot{V}O_2max$ was inversely associated with TG in men ($p<0.05$) and grip strength was negatively associated with FPG and metabolic risk score in women ($p<0.001$ and $p<0.05$, respectively), independently of waist circumference. Adjusting for visceral fat instead of waist circumference, similar results were obtained in women ($p<0.01$ and $p<0.05$, respectively), but the association between $\dot{V}O_2max$ and TG in men was attenuated to nonsignificant. This cross-sectional study demonstrates that muscular strength is inversely associated with plasma glucose levels and clustered metabolic risk factors independently of abdominal adiposity in Japanese women, but not in men. *J Physiol Anthropol 30(4): 133–139, 2011* http://www.jstage.jst.go.jp/browse/jpa2
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**Keywords:** metabolic syndrome, abdominal adiposity, cardiorespiratory fitness, muscular strength

## Introduction

Metabolic syndrome (MeS) is a cluster of visceral obesity, insulin resistance, hypertension, glucose intolerance, and dyslipidemia that substantially increases the risk of type 2 diabetes and cardiovascular disease (Alberti et al., 2006). MeS has a rising worldwide prevalence, and is largely related to increasing obesity, especially abdominal adiposity, along with a sedentary lifestyle. A recent report from the National Health and Nutrition Examination Survey (NHANES) 2003–2006 estimated that approximately 34% of the U.S. adult population has MeS (Ervin, 2009). According to the National Health and Nutrition Survey in 2008, approximately 22% of Japanese adult men and 11% of Japanese adult women have MeS (Ministry of Health, Labour and Welfare, 2009). Given the public health significance of MeS, successful strategies are urgently needed to intervene in its development.

Both low fitness (cardiorespiratory fitness (CRF) and muscular strength) and increased adiposity have increasingly been recognized as important risk factors associated with MeS in adults (Hassinen et al., 2008; LaMonte et al., 2005; Sayer et al., 2007). However, because low fitness and excess body fat often occur in combination, it is important to distinguish the separate effects on metabolic risk factors related to MeS. A few recent studies have examined the relative contribution of abdominal adiposity and CRF to metabolic risk, demonstrating that higher CRF and lower abdominal adiposity are each independently associated with a substantial reduction in metabolic risk related to MeS (Hassinen et al., 2008; Lee et al., 2005). However, few studies have investigated the independent contribution of muscular strength and abdominal fat to individual and clustered metabolic risk factors. A recent study by Wijndaele et al. (2007) has demonstrated that muscular strength is inversely related to a metabolic risk factor in women, even after adjustment for abdominal fat and other potential confounding factors. However, their studies have characterized abdominal fat by simple anthropometric measures such as waist circumference. A more recent study has revealed that reductions in visceral and total abdominal fat may occur in the absence of changes in waist circumference (Kay and Fiatarone, 2006). Thus, the insensitivity of anthropometric indexes to reflect actual amounts of visceral fat may contribute to over/underestimating the role of muscular strength in relation to abdominal fat with regard to their effects on metabolic risk factors.

Therefore, the purpose of the present study was to examine the relationship between fitness (CRF and muscular strength) and individual and clustered metabolic risk factors in Japanese men and women. Specifically, we investigated whether these associations are independent of abdominal adiposity quantified by direct measurement of visceral fat.

## Methods

*Subjects*

Two hundred twenty Japanese people (110 men and 110 women) aged 20 to 69 years participated in the present study. They were recruited through advertisements from students or faculty members of Waseda University and their immediate acquaintances. None of the subjects had been diagnosed with diabetes mellitus or were taking any medications that could affect the study variables. All subjects provided written informed consent before enrollment in the study. The research project was approved by the Ethical Committee of Waseda University.

*Fatness*

Body weight was measured using an electronic scale (Inner Scan BC-600, Tanita Co., Tokyo, Japan) and was determined to the nearest 0.1 kg. Height was measured to the nearest 0.1 cm using a stadiometer (YL-65, YAGAMI Inc., Nagoya, Japan). Body weight and height were measured with the subjects wearing light clothing and no shoes. Waist circumference (WC) was measured at the umbilical region with an inelastic measuring tape at the end of normal expiration to the nearest 0.1 cm. Visceral fat (VF) area was measured by magnetic resonance imaging (MRI) (Signa 1.5T, General Electric Co., Milwaukee, Wisconsin, USA). The imaging conditions included a T-1 weighted spin-echo and axial-plane sequence with a slice thickness of 10 mm, a repetition time (TR) of 140 ms, and an echo time of 12.3 ms. Cross-sectional images were scanned at the umbilical region (Usui et al., 2010). During the scan, the subjects were asked to hold their breath for about 30 s after inhalation to reduce the respiratory motion artifact. The magnetic resonance images were transferred to a personal computer in the Digital Imaging and Communications in Medicine (DICOM) file format, and the cross-sectional area of the VF at the umbilical region was determined using image-analysis software (Slice-o-matic 4.3 for Windows, Tomovision, Montreal, Canada). To minimize interobserver variation, all scans and analyses were performed by the same investigator, and the coefficient of variation was 0.4% for the cross-sectional areas of the umbilical region.

*Fitness*

*Cardiorespiratory fitness*

CRF was assessed by a maximal graded exercise test on a cycle ergometer (Monark Ergomedic 828E, Varberg, Sweden) and quantified as maximal oxygen uptake ($\dot{V}O_2max$). The initial workload was adjusted to 30–60 W, and the work rate was increased thereafter by 15 W/min until the subject could not maintain the required pedaling frequency of 60 rpm (Cao et al., 2010). Heart rate (Life Scope BSM-1101, NIHON KODEN Corp., Tokyo, Japan) and a rating of perceived exertion (RPE) were monitored throughout the exercise. During the progressive exercise test, the expired gas of subjects was collected and the rates of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured and averaged over 30-s intervals using an automated gas analyzing system (Aeromonitor AE-280S, Minato Medical Science, Tokyo, Japan). During the latter stages of the test, each subject was verbally encouraged by the test operators to give a maximal effort. The highest observed value of $\dot{V}O_2$ during the exercise test was considered to be the maximal oxygen uptake (mL/kg/min), and achievement of $\dot{V}O_2max$ was accepted if at least two of the following four criteria were achieved: the $\dot{V}O_2$ curve showed a leveling off, subject's maximal heart rate (HR) was >95% the age-predicted maximal HR (220-age), a respiratory exchange ratio in excess of 1.0, and the subject achieved an RPE of 19 or 20.

*Muscular strength*

Handgrip peak force was measured during maximal isometric contraction with a grip dynamometer (YX, YAGAMI Inc., Nagoya, Japan) in units of kilograms. Subjects were instructed to complete 2 handgrip contraction trials bilaterally, alternating hands between trails. Subjects held the dynamometer with the arm completely extended in standing position and were verbally encouraged by the assessor to exert the maximal force during each contraction trail. The higher grip strengths of two trials for each hand were summed to provide a single measure of grip strength. Grip strength was used as a proxy for overall strength (Rantanen et al., 1994).

*Metabolic risk factors*

Resting systolic and diastolic blood pressures (SBP and DBP) were measured using an automated recorder (HEM-759P, OMRON Corp., Kyoto, Japan). Blood samples were drawn between 8:00 a.m. and 11:00 a.m. after a 12-hour overnight fast for measurements of triglycerides (TG), HDL cholesterol (HDL-C), and fasting plasma glucose (FPG) levels. Serum and plasma samples were stored at −80°C until subsequent analyses. All blood parameters were analyzed by SRL, Inc. (Tokyo, Japan).

*Clustered metabolic risk factors*

In the present study, the gender-specific metabolic risk score (zMeS) was calculated, which is a continuous z score of 5 variables, for the risk factors of MeS (Franks et al., 2004). This variable was derived by standardizing and then summing the following values of WC, TG, inverse of HDL-C, blood pressure (SBP+DBP/2), and FPG. The standardizing of these factors was achieved by subtracting the sample mean from the individual mean and then dividing by the standard deviations

(SD). This continuously distributed metabolic risk score (zMeS) was also calculated without the adiposity component ($zMeS^{-WC}$). The calculating formula is as follows:

$$zMeS = zWC + zTG + zHDL\text{-}C + z(SBP + DBP/2) + zFPG$$

$$zMeS^{-WC} = zTG + zHDL\text{-}C + z(SBP + DBP/2) + zFPG$$

(z . standardized score)

### *Confounding variables*

Several confounding variables were included in the analyses: age, smoking status, and daily alcohol intake. Smoking status was assessed by means of a questionnaire, and was defined as one of two categories: never or current/former smoker. Daily alcohol intake (grams per day) over the past month was assessed using a brief-type self-administered diet history questionnaire (BDHQ) (Sasaki, 2004), which asked the average frequency and the usual serving size for each type of alcoholic beverage.

### *Statistical analyses*

Measured and calculated values are presented as means±SD. All subsequent analyses were carried out for men and women separately. The values of TG for both sexes and DBP in women were log transformed in correlation analyses due to their nonnormal distribution. The Student's *t*-test was used to determine differences between men and women. Pearson's product correlations were calculated among the outcome variables (age, BMI, WC, VF, $\dot{V}O_2max$, grip strength, TG, HDL-C, SBP, DBP, FPG, and zMeS). Multiple linear regression models were used to assess the association of fatness and fitness with metabolic risk. We first entered the fitness ($\dot{V}O_2max$ or grip strength) and BMI for independent variables and zMeS for a dependent variable (model A). We then entered the fitness ($\dot{V}O_2max$ or grip strength) and a parameter for abdominal fat (WC or VF) for independent variables and each metabolic risk factor or $zMeS^{-WC}$ for a dependent variable (model B and C). All models were adjusted for confounding variables: age, smoking status, and alcohol intake and are presented as standardized $\beta$ coefficients. All analyses were completed using SPSS 17.0J for Windows (SPSS Japan Inc., Tokyo, Japan). The statistical significance level was set at $p<0.05$.

## Results

The characteristics of men and women are shown in Table 1. Men showed higher BMI, WC, and VF in comparison with

**Table 1** The characteristics of subjects

| Variables | Women (n=110) | Men (n=110) | $p$ |
|---|---|---|---|
| Age (yrs) | 44.3±13.6 | 43.4±13.5 | 0.605 |
| Height (cm) | 158.0± 5.2 | 171.5± 6.4 | <0.001 |
| Body weight (kg) | 53.8± 7.0 | 70.6±11.0 | <0.001 |
| BMI (kg/m²) | 21.6± 2.8 | 24.0± 3.2 | <0.001 |
| WC (cm) | 76.8± 8.9 | 83.7± 8.8 | <0.001 |
| VF (cm²) | 53.1±31.5 | 93.6±47.4 | <0.001 |
| $\dot{V}O_2max$ (mL/kg/min) | 27.7± 4.8 | 35.1± 6.6 | <0.001 |
| Grip strength (kg) | 54.7± 9.3 | 89.4±12.8 | <0.001 |
| TG (mg/dL) | 72.1±38.6 | 108.6±67.8 | <0.001 |
| HDL-C (mg/dL) | 67.8±13.6 | 58.6±13.1 | <0.001 |
| SBP (mmHg) | 117.2±16.0 | 125.5±14.5 | <0.001 |
| DBP (mmHg) | 74.0± 9.9 | 80.5±11.0 | <0.001 |
| FPG (mg/dL) | 89.4± 8.3 | 93.0± 9.1 | 0.002 |
| Current or former smokers (%) | 14 | 41 | <0.001 |
| Alcohol intake≧20 g/day (%) | 11 | 46 | <0.001 |

Data are means±SD or proportions.
BMI, body mass index; WC, waist circumference; VF, visceral fat; $\dot{V}O_2max$, maximal oxygen uptake; TG, triglycerides; HDL-C, HDL cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose.

**Table 2** Correlation matrix of age, fatness (BMI, WC, and VF), fitness ($\dot{V}O_2max$ and grip strength), and individual and clustered metabolic risk factors

| Variables | Women (n=110) | | | | | | Men (n=110) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age (yrs) | BMI (kg/m²) | WC (cm) | VF (cm²) | $\dot{V}O_2max$ (mL/kg/min) | Grip strength (kg) | Age (yrs) | BMI (kg/m²) | WC (cm) | VF (cm²) | $\dot{V}O_2max$ (mL/kg/min) | Grip strength (kg) |
| BMI (kg/m²) | 0.17 | — | | | | | 0.00 | — | | | | |
| WC (cm) | 0.31** | 0.78*** | — | | | | 0.20* | 0.90*** | — | | | |
| VF (cm²) | 0.43*** | 0.74*** | 0.72*** | — | | | 0.26** | 0.71*** | 0.80*** | — | | |
| $\dot{V}O_2max$ (mL/kg/min) | −0.38*** | −0.17 | −0.32** | −0.38*** | — | | −0.44*** | −0.47*** | −0.55*** | −0.59*** | — | |
| Grip strength (kg) | −0.34*** | −0.02 | −0.10 | −0.19* | 0.35*** | — | −0.20* | 0.12 | 0.09 | 0.01 | 0.19 | — |
| TG (mg/dL) | 0.37*** | 0.32** | 0.42*** | 0.43*** | −0.26** | −0.15 | 0.15 | 0.49*** | 0.53*** | 0.60*** | −0.44*** | −0.01 |
| HDL-C (mg/dL) | 0.13 | −0.22* | −0.14 | −0.16 | 0.11 | 0.05 | 0.08 | −0.36*** | −0.32** | −0.26** | 0.19* | 0.03 |
| SBP (mmHg) | 0.53*** | 0.38*** | 0.47*** | 0.52*** | −0.33*** | −0.18 | 0.36*** | 0.24* | 0.28** | 0.24* | −0.18 | 0.04 |
| DBP (mmHg) | 0.37*** | 0.32** | 0.44*** | 0.37*** | −0.27** | −0.11 | 0.31** | 0.30** | 0.36*** | 0.40*** | −0.27** | 0.01 |
| FPG (mg/dL) | 0.52*** | 0.29** | 0.37*** | 0.41*** | −0.29** | −0.43*** | 0.33*** | 0.13 | 0.20* | 0.18 | −0.12 | 0.05 |
| zMeS | 0.46*** | 0.62*** | — | — | −0.39*** | −0.28* | 0.29* | 0.71*** | — | — | −0.46*** | 0.08 |

TG and DBP were log transformed for analyses.
BMI, body mass index; WC, waist circumference; VF, visceral fat; $\dot{V}O_2max$, maximal oxygen uptake; TG, triglycerides; HDL-C, HDL cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; zMeS, metabolic risk score.
* $p<0.05$; ** $p<0.01$; *** $p<0.001$.

women ($p<0.001$). Both $\dot{V}O_2max$ and grip strength were significantly higher in men than in women ($p<0.001$). TG, SBP, DBP, and FPG were higher in men (FPG: $p<0.01$, expect for FPG: $p<0.001$), whereas HDL-C was higher in women ($p<0.001$).

Table 2 shows the Pearson correlations matrix of individual and clustered metabolic risk factors and fatness (BMI, WC, and VF) and fitness ($\dot{V}O_2max$ and grip strength) in men and women. Age correlated positively with SBP, DBP, FPG, and zMeS in men and women ($p<0.05$) and additionally with TG in women ($p<0.001$). Significant correlations were obtained between individual metabolic risk factors and all three measures of fatness except for FPG in men and HDL-C in women ($p<0.05$). Positive correlations were obtained between zMeS and BMI in men and women. $\dot{V}O_2max$ was significantly correlated with TG, HDL-C, DBP, and zMeS in men ($p<0.05$) and with TG, SBP, DBP, FPG, and zMeS in women ($p<0.01$). Grip strength was negatively correlated with FPG and zMeS in women ($p<0.05$), but no significant correlations were obtained between grip strength and any of the metabolic risk factors or zMeS in men.

Table 3 presents the results of multiple linear regression analyses of clustered metabolic risk factors (zMeS) controlled for age, smoking status, and alcohol intake, including the contribution of BMI (model A). Model A revealed that $\dot{V}O_2max$ and grip strength were inversely associated with zMeS independently of BMI in women ($p<0.05$), but not in men.

Table 4 presents the results of multiple linear regression analyses of individual and clustered metabolic risk factors ($zMeS^{-WC}$) controlled for age, smoking status, and alcohol intake, including the contribution of WC (model B) and VF (model C). Model B shows that $\dot{V}O_2max$ was inversely associated with TG in men ($p<0.05$) and that grip strength was negatively associated with FPG ($p<0.001$) and $zMeS^{-WC}$ ($p<0.05$) in women independently of WC. Controlling for VF instead of WC (model C) revealed similar results for grip strength in women (FPG: $p<0.01$, $zMeS^{-WC}$: $p<0.05$); however, the association between $\dot{V}O_2max$ and TG in men became nonsignificant ($p=0.14$).

**Table 3** Association of BMI and the fitness ($\dot{V}O_2max$ or grip strength) with the clustered metabolic risk factors (zMeS)

| Model A | BMI (kg/m$^2$) | $\dot{V}O_2max$ (mL/kg/min) | BMI (kg/m$^2$) | Grip strength (kg) |
|---|---|---|---|---|
| Women | 0.55*** | −0.19* | 0.58*** | −0.18* |
| Men | 0.71*** | 0.00 | 0.70*** | 0.05 |

Date are standardized $\beta$ coefficients.
All models were adjusted for age, smoking habit, and alcohol intake.
$\dot{V}O_2max$, maximal oxygen uptake; zMeS, metabolic risk score.
*$p<0.05$; ***$p<0.001$.

**Table 4** Association of a measure of abdominal adiposity (WC or VF) and the fitness ($\dot{V}O_2max$ or grip strength) with the individual and clustered metabolic risk factors ($zMeS^{-WC}$)

| Model B | Women | | | | Men | | | |
|---|---|---|---|---|---|---|---|---|
| | WC (cm) | $\dot{V}O_2max$ (mL/kg/min) | WC (cm) | Grip strength (kg) | WC (cm) | $\dot{V}O_2max$ (mL/kg/min) | WC (cm) | Grip strength (kg) |
| TG (mg/dL) | 0.33*** | −0.05 | 0.34*** | −0.02 | 0.42*** | −0.23* | 0.54*** | −0.07 |
| HDL-C (mg/dL) | −0.19 | 0.15 | −0.23* | 0.15 | −0.28** | 0.12 | −0.35*** | 0.06 |
| SBP (mmHg) | 0.31*** | −0.08 | 0.33*** | 0.01 | 0.29** | 0.13 | 0.22* | 0.07 |
| DBP (mmHg) | 0.34*** | −0.06 | 0.35*** | 0.04 | 0.32** | 0.00 | 0.32*** | 0.01 |
| FPG (mg/dL) | 0.21* | −0.06 | 0.24** | −0.30*** | 0.21 | 0.16 | 0.12 | 0.11 |
| $zMeS^{-WC}$ | 0.43*** | −0.12 | 0.46*** | −0.19* | 0.54*** | 0.00 | 0.53*** | 0.05 |

| Model C | Women | | | | Men | | | |
|---|---|---|---|---|---|---|---|---|
| | VF (cm$^2$) | $\dot{V}O_2max$ (mL/kg/min) | VF (cm$^2$) | Grip strength (kg) | VF (cm$^2$) | $\dot{V}O_2max$ (mL/kg/min) | VF (cm$^2$) | Grip strength (kg) |
| TG (mg/dL) | 0.31** | −0.05 | 0.33** | 0.00 | 0.53*** | −0.16 | 0.61*** | −0.03 |
| HDL-C (mg/dL) | −0.26* | 0.13 | −0.29** | 0.14 | −0.31** | 0.09 | −0.36*** | 0.04 |
| SBP (mmHg) | 0.34*** | −0.07 | 0.35*** | 0.03 | 0.17 | 0.07 | 0.13 | 0.10 |
| DBP (mmHg) | 0.22* | −0.09 | 0.24* | 0.05 | 0.33** | 0.01 | 0.32*** | 0.04 |
| FPG (mg/dL) | 0.20* | −0.06 | 0.21* | −0.28** | 0.17 | 0.14 | 0.09 | 0.12 |
| $zMeS^{-WC}$ | 0.44*** | −0.12 | 0.47*** | −0.16* | 0.55*** | 0.02 | 0.53*** | 0.09 |

Date are standardized $\beta$ coefficients.
All models were adjusted for age, smoking habit, and alcohol intake.
TG and DBP were log transformed for analyses.
WC, waist circumference; VF, visceral fat; $\dot{V}O_2max$, maximal oxygen uptake; TG, triglycerides; HDL-C, HDL cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; $zMeS^{-WC}$, metabolic risk score without WC factor.
*$p<0.05$; **$p<0.01$; ***$p<0.001$.

**Discussion**

This cross-sectional study was performed to examine whether fitness is associated with individual and clustered metabolic risk factors independently of abdominal adiposity in Japanese men and women aged 20–69. The principal finding of this study was that both grip strength and abdominal adiposity are each independently associated with individual and clustered metabolic risk factors in women, but not in men (Table 3). Previous studies have indicated that muscular strength is a significant predictor of metabolic risk in adults (Sayer et al., 2007; Wijndaele et al., 2007). However, few studies have evaluated the independent importance of abdominal adiposity and fitness (Sayer et al., 2007). An important issue to consider is that low fitness and excess body fat often occur in combination. In fact, grip strength was negatively correlated with VF in women ($r=-0.19$, $p<0.05$) in the present study (Table 2). To elucidate the role of muscular strength in metabolic risk, it is important to examine these relationships, including the contribution of abdominal adiposity. Wijndaele et al. (2007) have reported that muscular strength assessed by measuring isometric knee extension and flexion peak torque is associated with a metabolic risk factor even after controlling for abdominal adiposity in women. This finding is roughly in accordance with our results, although in their study the abdominal fat indicator depended on simple anthropometric measures such as WC, which does not always reflect the accumulation of VF (Kay and Fiatarone, 2006). We found that muscular strength is associated with metabolic risk independent of WC and additionally with abdominal adiposity quantified by MRI, which is a direct measurement of VF. Therefore, this result supports the position that increasing muscular strength levels may be an effective strategy for preventing MeS in women.

As seen in Table 3, physical fitness ($\dot{V}O_2$max and grip strength) was found to be significantly and inversely associated with zMeS after controlling for BMI only in women (model A). In men, low levels of fitness did not appear to be a direct and primary cause of clustered metabolic risk factors. These results indicate that the effects of physical fitness, as measured by CRF and muscular strength, on clustered metabolic risk factors differ between men and women, and that the role of fitness may be more important in women than in men in the prevention of MeS. However, BMI is an indicator of general obesity and does not reflect abdominal adiposity, although these variables are highly correlated (Table 2). We therefore examined these associations using abdominal fat indicators.

In the present study, abdominal adiposity was found to be a stronger predictor of all metabolic risk factors than $\dot{V}O_2$max in men and women (Table 4). These data support a study by Christou et al. (2005), where it was reported that body fatness is a better predictor of the cardiovascular disease risk factor profile than CRF. In the present study, however, $\dot{V}O_2$max was associated with TG independently of WC in men (model B). The reason why CRF is predictive of TG only in men remains to be elucidated, but the effect of CRF on metabolic risk may be overestimated in men in the model B. Men generally have more VF than women (Boule et al., 2005) due to the lack of a possible protective effect of estrogen in men compared with women (Geer and Shen, 2009). However, WC can not distinguish VF from subcutaneous fat. Thus, the insensitivity of the anthropometric index in reflecting actual amounts of VF may contribute to overestimating the role of CRF in relation to abdominal fat with regard to metabolic risk. As such, we investigated the relative contribution of VF, as assessed by MRI, to metabolic risk (model C).

In model C, the association of $\dot{V}O_2$max with TG was attenuated to nonsignificant in men. Previous studies have indicated that abdominal fat, as measured by computed tomography, and CRF are significant predictors of several metabolic risk factors related to dyslipidemia in adults (Boule et al., 2005; Nagano et al., 2004). However, these associations were not found in the present study. The methodological difference in evaluating CRF may lead to different results. In previous studies (Boule et al., 2005; Nagano et al., 2004) CRF was not measured directly, whereas in our study $\dot{V}O_2$max was assessed directly using a respiratory gas exchange analysis during a maximal cycle ergometer test, which is an accurate and highly reproducible measure of CRF. The results of the present study suggest that preventing abdominal fat accumulation rather than increasing CRF levels appears to be a more effective and direct strategy for the primary prevention of MeS in both men and women.

The main finding of this study was that grip strength is associated with FPG independently of WC or VF in women. Grip strength is a simple and direct isometric method for the assessment of hand and forearm skeletal muscular strength, which may be representative of overall muscular strength because it is highly correlated with other muscular strength measures, including elbow flexion, knee extension, trunk flexion, and trunk extension (Rantanen et al., 1994). Sayer et al. (2005) have indicated that there is a graded association between increased glucose levels and weaker muscular strength in those with impaired glucose tolerance and normal blood glucose levels. As such, there appears to be a link between muscular strength and glucose metabolism. Because muscular strength is related to skeletal muscle mass, which is a significant site of glucose disposal (Lazarus et al., 1997), muscular strength may be important for glucose metabolism and could be a good target for the treatment of metabolic risk leading to conditions such hyperglycemia and type 2 diabetes mellitus. The amount of physical activity is also found to be related to muscular fitness (Paalanne et al., 2009). Actually, grip strength in subjects with exercise habits is known to be higher than those without exercise habits (Miyatake et al., 2009). Previous studies have shown that increase in moderate and vigorous activity results in a decrease in fasting insulin level, a marker of insulin resistance (Assah et al., 2008), indicating physical activity exerts its action on glucose metabolism in the long term.

Taken together, these results suggest that the association of muscular strength with FPG may bepartially explained by physical activity. It should be noted that in the present study, grip strength ($\beta = -0.28$, $p < 0.01$) was a strong predictor of FPG as much as VF ($\beta = 0.21$, $p < 0.05$) in women (model C). It is therefore plausible that increasing the levels of muscular strength as well as preventing VF accumulation may be equally effective in preventing hyperglycemia and type 2 diabetes mellitus.

It is interesting that grip strength was not found to be predictive of FPG in men (Table 3). Differences in muscular strength are known to exist between men and women, and from early adulthood, women have on average 35% to 45% less muscular strength than men (Katzmarzyk and Craig, 2002; Ministry of Education, Culture, Sports, Science and Technology, 2010). Thus absolutely lower muscular strength for women compared with men might explain the sex difference in the association between grip strength and FPG. Because fasting glucose is known to be a predictor of new onset diabetes mellitus (Chen et al., 2009), poor muscular strength in women can be considered a marker for risk of type 2 diabetes.

The present study has several limitations. First, as it was a cross-sectional study; larger sample sizes and prospective and interventional studies are needed to confirm the effects of muscular strength on metabolic risk independent of abdominal fat accumulation. Second, the results may have limited generalizability due to ethnic differences in muscular strength. Japanese generally have lower muscular strength than Westerners, so the relationship between muscular strength and metabolic risk in other racial groups may differ from that found in our study. While this remains to be investigated, this study has contributed valuable information for Japanese. Third, because the prevalence of type 2 diabetes is much lower in Japanese women than in Japanese men, the findings in the present study must be adopted carefully for women. However, type 2 diabetes occurs in Asians who are less obese than those in Western countries (Chan et al., 2009) and the incidence is increasing continuously in both Japanese men and women. As such, maintenance of good muscular strength by regular daily exercise (Miyatake et al., 2009) appears to be important in the prevention of diabetes in Japanese women.

In summary, the present study suggests that there are sex differences in associations of physical fitness and fatness with metabolic risk in Japanese adults. The role of physical fitness (CRF and muscular strength) appears to be more important in women than in men in the prevention of MeS. In men, abdominal adiposity is a stronger predictor of individual and clustered metabolic risk factors than fitness. In women, muscular strength and abdominal adiposity are each independently associated with FPG and clustered metabolic risk factors. Muscular strength in women is a strong predictor of FPG as much as VF accumulation. The present study implies that effective approaches to preventing MeS may differ between men and women, and that exercise to increase muscular strength should be incorporated into individual lifestyles to reduce the risk of MeS and diabetes mellitus in women.

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# Validity of Predictive Equations for Basal Metabolic Rate in Japanese Adults

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

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

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

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

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

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Table 1. Physical characteristics of subjects.

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

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

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

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

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

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

## MATERIALS AND METHODS

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

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

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

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

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

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

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

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

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

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

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

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

## RESULTS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

## DISCUSSION

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

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

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

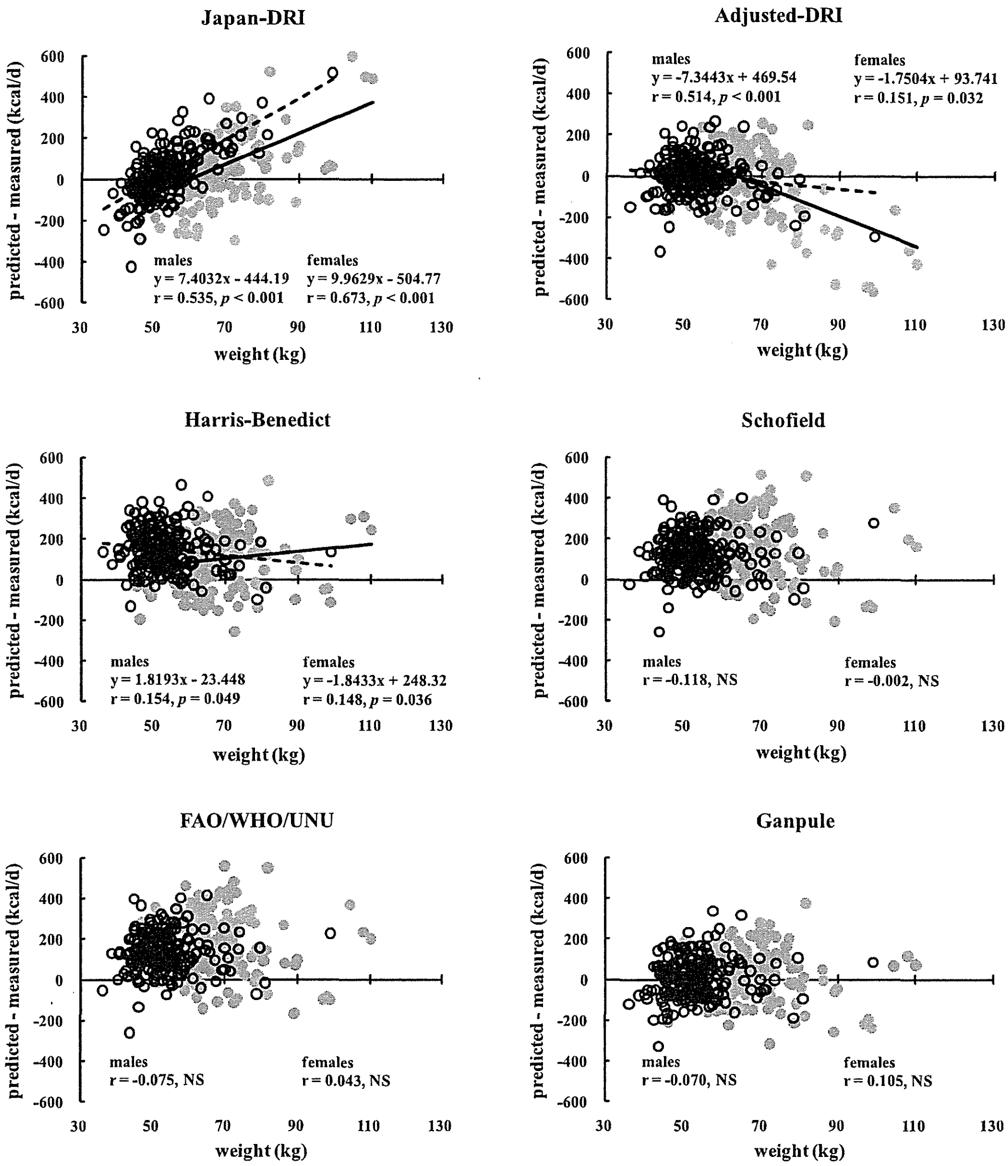


Fig. 1. Relationship between difference of basal metabolic rate (predicted minus measured basal metabolic rate) and weight in males and females. Males, black circle (●) and straight line (——); females, white circle (○) and dashed line (- - -).

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

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

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

The mean differences in BMR between the Japan-DRI in both sexes and Adjusted-DRI equations in males were highly influenced by weight. For individuals with larger body weight, the difference between predicted BMR by Japan-DRI equations and measured BMR was larger in both sexes, while the difference by Adjusted-DRI equations was smaller and negative in males with larger body weight. For Harris-Benedict equations in both sexes and the Adjusted-DRI equation in females, the effect of body weight on the prediction error was small but significant, as also reported by Tanaka et al. (*38*) for obese subjects. Yamamura and Kashiwazaki (*31*) reported that, for lean subjects ($BMI \leq 18.4\ kg/m^2$) 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 ($18.5\ kg/m^2 \leq BMI \leq 24.9\ kg/m^2$). 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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REGULAR ARTICLE

# Evaluation of anthropometric parameters and physical fitness in elderly Japanese

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**Abstract**
*Objectives* We evaluated anthropometric parameters and physical fitness in elderly Japanese.
*Methods* A total of 2,106 elderly Japanese (749 men and 1,357 women), aged 60–79 years, were enrolled in a cross-sectional investigation study. Anthropometric parameters and physical fitness, i.e., muscle strength and flexibility, were measured. Of the 2,106 subjects, 569 subjects (302 men and 267 women) were further evaluated for aerobic exercise level, using the ventilatory threshold (VT).
*Results* Muscle strength in subjects in their 70s was significantly lower than that in subjects in their 60s in both sexes. Two hundred and twenty-nine men (30.6%) and 540 women (39.8%) were taking no medications. In men, anthropometric parameters were significantly lower and muscle strength, flexibility, and work rate at VT were significantly higher in subjects without medications than these values in subjects with medications. In women, body weight, body mass index (BMI), and abdominal circumference were significantly lower, and muscle strength was significantly higher in subjects without medications than these values in subjects with medications.
*Conclusion* This mean value may provide a useful database for evaluating anthropometric parameters and physical fitness in elderly Japanese subjects.

**Keywords** Elderly Japanese · Anthropometric parameters · Muscle strength · Ventilatory threshold (VT)

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## Introduction

The proportion of elderly people (over the age of 65 years) in Japan has increased and this has become a public health challenge in Japan. For example, in Japan, 28,216,000 people (22.1% of the population) are reported to be over the age of 65 [1].

It has been shown that obese subjects have a high mortality rate [2] and have associated atherogenic risk factors, such as hypertension, coronary heart disease, diabetes mellitus, and dyslipidemia [3, 4]. In addition, Sandvik et al. reported that physical fitness was a graded, independent, long-term predictor of mortality from cardiovascular causes in healthy, middle-aged men [5]. Also, Metter et al. [6] reported that lower and declining muscle strength was associated with increased mortality, independent of physical activity and muscle mass. In order to provide proper management and control of anthropometric parameters and physical fitness in elderly Japanese, precise assessments of these parameters are necessary. However, the evaluation of anthropometric parameters and physical fitness still remains to be investigated in elderly Japanese who are not taking medications.

Therefore, we evaluated anthropometric parameters and physical fitness in elderly Japanese and compared these parameters in subjects with and without medications.

## Subjects and methods

### Subjects

We used data for all 2,106 elderly subjects (749 men and 1,357 women), aged 60–79 years, among 16,383 subjects in a cross-sectional investigation study. All subjects met the following criteria: (1) they had been wanting to change their lifestyle i.e., diet and exercise habits, and had received an annual health checkup between June 1997 and December 2009 at Okayama Southern Institute of Health; (2) their anthropometric, muscle strength, and flexibility measurements had been taken as part of their annual health checkups; and (3) they provided written informed consent (Table 1).

In a second analysis, among the 2,106 subjects, we further examined the data on 569 subjects (302 men and 267 women) who undertook measurements of aerobic exercise level; we also examined anthropometric, muscle strength, and flexibility measurements in these second-analysis subjects (Table 2).

The study was approved by the Ethics Committee of Okayama Health Foundation.

### Athropometric measurements

The anthropometric parameters were evaluated by using the following parameters: height, body weight, body mass index (BMI), abdominal circumference, and hip circumference. BMI was calculated as weight/[height]$^2$ (kg/m$^2$). The abdominal circumference was measured at the umbilical level and the hip was measured at the widest circumference over the trochanter in standing subjects after normal expiration [7].

### Muscle strength

To assess muscle strength, grip and leg strength were measured. Grip strength was measured using the THP-10 (SAKAI, Tokyo, Japan) device, while leg strength was measured with a dynamometer (COMBIT CB-1; MINATO Co., Osaka, Japan). Isometric leg strength was measured as follows: the subject sat in a chair, grasping the armrest in order to fix the body position. The dynamometer was then attached to the subject's ankle joint with a strap. Next, the subject extended the leg to 60° [8]. To standardize the influence of the total body weight, we calculated the muscle strength (kg) per body weight (kg) [9].

### Flexibility

Flexibility was measured as follows in all the participants. Sit-and-reach measurements were obtained to assess the overall flexibility in forward flexion, with the measurements recorded as the distance (in cm) between the fingertips and toes. The subject's knees were kept straight throughout the test and ankles were maintained at 90° by having the soles of the feet pressed against a board perpendicular to the sitting surface [10].

### Oxygen uptake at ventilatory threshold (VT)

A graded ergometer exercise protocol [11] had been carried out at the subjects' checkups. After breakfast (2 h), resting

**Table 1** Clinical profiles of subjects enrolled in the first analysis

| | Men ($n$ = 749) | | | Women ($n$ = 1,357) | | |
|---|---|---|---|---|---|---|
| | Mean ± SD | Minimum | Maximum | Mean ± SD | Minimum | Maximum |
| Age (years) | 65.6 ± 4.6 | 60 | 79 | 64.9 ± 4.2 | 60 | 79 |
| Height (cm) | 164.4 ± 5.5 | 145.3 | 180.2 | 151.9 ± 5.0 | 136.2 | 167.0 |
| Body weight (kg) | 65.9 ± 9.3 | 40.1 | 112.2 | 55.3 ± 7.9 | 33.4 | 97.3 |
| Body mass index (kg/m$^2$) | 24.3 ± 3.0 | 16.2 | 40.9 | 24.0 ± 3.2 | 15.4 | 41.9 |
| Abdominal circumference (cm) | 86.1 ± 9.2 | 61.6 | 127.0 | 78.8 ± 9.3 | 54.7 | 121.6 |
| Hip circumference (cm) | 91.9 ± 5.5 | 77.8 | 122.7 | 90.3 ± 5.4 | 69.0 | 120.5 |
| Right grip strength (kg) | 36.4 ± 7.0 | 8.7 | 60.0 | 22.3 ± 4.6 | 4.9 | 39.9 |
| Left grip strength (kg) | 35.0 ± 6.9 | 5.0 | 55.7 | 21.4 ± 4.5 | 4.3 | 47.4 |
| Leg strength (kg) | 51.0 ± 13.4 | 11.7 | 97.0 | 35.3 ± 8.6 | 10.7 | 69.7 |
| Leg strength per body weight | 0.78 ± 0.19 | 0.20 | 1.50 | 0.65 ± 0.17 | 0.15 | 1.26 |
| Flexibility (cm) | 0.6 ± 10.3 | −34.0 | 28.3 | 11.2 ± 8.1 | −22.0 | 28.4 |
| Number of subjects without medications (%) | 229 (30.6) | | | 540 (39.8) | | |

**Table 2** Clinical profiles of subjects enrolled in the second analysis

| | Men ($n = 302$) | | | Women ($n = 267$) | | |
|---|---|---|---|---|---|---|
| | Mean ± SD | Minimum | Maximum | Mean ± SD | Minimum | Maximum |
| Age (years) | 65.3 ± 4.3 | 60 | 79 | 64.7 ± 4.0 | 60 | 77 |
| Height (cm) | 164.6 ± 5.1 | 149.1 | 178.3 | 152.4 ± 4.2 | 142.2 | 164.2 |
| Body weight (kg) | 68.6 ± 9.7 | 47.6 | 112.2 | 59.3 ± 8.8 | 37.6 | 97.3 |
| Body mass index (kg/m$^2$) | 25.3 ± 3.1 | 18.9 | 40.9 | 25.5 ± 3.7 | 16.7 | 41.9 |
| Abdominal circumference (cm) | 88.8 ± 9.8 | 62.5 | 127.0 | 83.4 ± 10.6 | 60.0 | 121.6 |
| Hip circumference (cm) | 93.2 ± 6.0 | 79.7 | 122.7 | 92.4 ± 6.4 | 72.5 | 120.5 |
| Right grip strength (kg) | 36.3 ± 6.8 | 13.4 | 60.0 | 22.1 ± 4.7 | 6.6 | 34.9 |
| Left grip strength (kg) | 35.1 ± 6.4 | 15.6 | 54.1 | 21.2 ± 4.5 | 6.9 | 33.0 |
| Leg strength (kg) | 51.0 ± 13.1 | 19.0 | 92.0 | 35.2 ± 9.0 | 11.0 | 69.7 |
| Leg strength per body weight | 0.75 ± 0.19 | 0.26 | 1.17 | 0.60 ± 0.15 | 0.16 | 1.08 |
| Flexibility (cm) | −0.9 ± 10.1 | −34.0 | 23.7 | 9.7 ± 8.3 | −22.0 | 26.4 |
| Oxygen uptake at VT (ml/kg/min) | 12.5 ± 2.0 | 5.9 | 21.6 | 11.9 ± 1.7 | 7.6 | 16.8 |
| Work rate at VT (watt) | 53.6 ± 13.8 | 5.0 | 100.0 | 38.7 ± 10.5 | 5.0 | 70.0 |
| Heart rate at VT (beats/min) | 95.7 ± 12.9 | 64.0 | 146.0 | 99.0 ± 12.8 | 67.0 | 137.0 |
| Number of subjects without medications (%) | 33 (10.9) | | | 55 (20.6) | | |

*VT* ventilatory threshold

ECG was recorded and blood pressure was measured. All subjects were then given a graded exercise after 3 min of pedaling on an unloaded bicycle ergometer (Excalibur V2.0; Lode, Groningen, The Netherlands). The profile of incremental workloads was automatically defined by the methods of Jones et al. [11], in which the workloads reach the predicted maximum rate of oxygen consumption ($\dot{V}O_{2max}$) in 10 min. A pedaling cycle of 60 rpm was maintained. Loading was terminated when the appearance of symptoms forced the subject to stop. During the test, ECG was monitored continuously, together with recording of the heart rate. Expired gas was collected, and rates of oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured breath-by-breath using a cardiopulmonary gas exchange system (Oxycon Alpha; Mijnhrdt, The Netherlands). The VT was determined by the standards of Wasserman et al. [12] and Davis et al. [13], and the V-slope method of Beaver et al. [14] from $\dot{V}O_2$, $\dot{V}CO_2$, and minute ventilation (VE).

### Medications

The data on medications were obtained at interviews conducted by well-trained staff using a structured method. The subjects were asked if they were currently taking medications, i.e., those for diabetes, hypertension, dyslipidemia, and/or orthopedic diseases. When the answer was "yes", they were classified as subjects with medications. When the answer was "no", they were classified as subjects without medications.

### Statistical analysis

Data are expressed as means ± standard deviation (SD) values. There were sufficient numbers of subjects, except for subjects in their 70s without medications in the second analysis. A comparison of parameters between subjects in their 60s and those in their 70s, between subjects with and without medications, and between subjects in their 60s and those in their 70s without medications was made using an unpaired *t*-test: $p < 0.05$ was considered to be statistically significant.

## Results

Clinical profiles of the subjects in the first and second analyses are summarized in Tables 1 and 2. Two hundred and twenty-nine men (30.6%) and 540 women (39.8%) in the first analysis and 33 men (10.9%) and 55 women (20.6%) in the second analysis were not taking medications.

We compared the clinical parameters between subjects in their 60s and those in their 70s (Table 3). In men, height, body weight, BMI, and hip circumference in those in their 60s were significantly higher than the values in men in their 70s. However, abdominal circumference in men in their 60s was similar to that in men in their 70s. Muscle strength, flexibility, oxygen uptake at VT, work rate at VT, and heart rate at VT in men in their 60s were higher than the values in men in their 70s. In women, height was significantly