Table 1 Physical characteristics of subjects

	Young (n = *61)*	*Middle* (n = *49)*	*Old* (n = *28)*
Age (years)	23.7 ± 0.5	58.3 ± 0.6^{a}	70.3 ± 0.7^{a,b}
Age at menopause (years)		50.0 ± 0.6	50.1 ± 0.9
Years since menopause		8.3 ± 0.7	20.2 ± 1.1^{b}
Serum estradiol (pg ml ^{1})	86.4 ± 8.2	11.4 ± 0.3^{a}	11.8 ± 0.4^{a}
Osteocalcin (pg ml ^{1})	5.47 ± 0.3	9.7 ± 0.4^{a}	9.9 ± 0.6^{a}
Body mass (kg)	51.8 ± 0.7	55.4 ± 1.0^{a}	52.6 ± 1.0^{b}
BMI (kg m ^{2})	20.2 ± 0.2	23.3 ± 0.4^{a}	22.6 ± 0.5^{a}
Percent body fat (%)	24.6 ± 0.6	31.2 ± 0.9^{a}	30.3 ± 0.7^{a}
*V*O$_2$peak (ml kg ^{1} min ^{1})	33.8 ± 0.7	29.3 ± 0.7^{a}	24.6 ± 0.8^{a,b}
Handgrip strength (kg)	28.9 ± 0.7	27.2 ± 0.6	23.4 ± 0.7^{a,b}
Leg extension power (W kg ^{1})	17.3 ± 0.6	13.8 ± 0.5^{a}	12.5 ± 0.7^{a}
Physical activity scale	4.2 ± 0.2	4.7 ± 0.2	4.2 ± 0.3

Abbreviations: BMI, body mass index; *V*O$_2$peak, peak oxygen uptake.
Data are presented as means ± s.e.m.
[a]Significantly different from young, $P<0.05$.
[b]Significantly different from middle-aged, $P<0.05$.

the body as described previously by Abe *et al.* (1994). The sites were lateral forearm, anterior and posterior upper arm, abdomen, subscapula, anterior and posterior thigh, and anterior and posterior lower leg. Ultrasonographic evaluation of MTH was performed using a real-time linear electronic scanner with a 5 MHz scanning head (SSD-500; Aloka, Tokyo, Japan). The scanning head with water-soluble transmission gel was placed perpendicular to the tissue interface at the marked sites and provided acoustic contact without depression of the skin surface. MTHs were measured directly from the screen with electronic callipers, and determined as a distance from the adipose tissue–muscle interface to the muscle–bone interface. Whole-body and regional SM mass were estimated using the equations of Sanada *et al.* (2006). MTHs were converted to mass units in kilograms by ultrasound-derived prediction equations using site-matched MTH × height, which were then used to calculate arm, trunk, thigh and lower leg SM mass. The reliability of image reconstruction and distance measurements were confirmed by comparing the ultrasonic and manual measurements of tissue thickness in human cadavers, and the coefficient of variation for the MTH measurements was 1% (Kawakami *et al.*, 1993).

Measurement of fitness values

The peak oxygen uptake (*V*O$_2$peak) was measured by an incremental cycle exercise test using a cycle ergometer (Monark, Varberg, Sweden). The subjects were encouraged during the ergometer test to exercise at the level of maximum intensity. Subjects breathed through a low-resistance two-way valve, and the expired air was collected in Douglas bags. Expired O$_2$ and CO$_2$ gas concentrations were measured by mass spectrometry (WSMR-1400; Westron, Chiba, Japan), and gas volume was determined using a dry gas metre (NDS-2A-T; Shinagawa Dev., Tokyo, Japan). The system of mass spectrometer was calibrated during every measurement by the standard reference gas. The highest value of *V*O$_2$ during the exercise test was designated as *V*O$_2$peak.

Leg extension power was measured with an isokinetic leg power system (Anaero Press 3500; Combi wellness, Tokyo, Japan) in the sitting position. Handgrip strength of the right upper limb was measured with a hand-held dynamometer, with the subject standing and arms extended by their side.

Statistical analysis

All measurements and calculated values are expressed as the mean ± s.e.m. We compared the mean values of general criteria, bone mineral indices, body composition values and fitness values among the three age groups using one-way analysis of variance with body mass index (BMI) adjusted for the covariate. In cases with a significant F-value, a *post-hoc* test using the Newman–Keuls method was used to identify significant differences among the mean values. Pearson's product correlations were calculated between LSTM, SM mass or fitness values and bone mineral indices. The α level for testing significance was set at $P<0.05$. All statistical analyses were performed using Stat View v5.0 for Windows (SYS Institute).

Results

The physical characteristics of the subjects are presented in Table 1. The BMI and body fat percentage in MW and OW were significantly higher than those in YW ($P<0.05$). There were no significant differences in the NASA/JSC physical activity scale among the groups. Serum estradiol in MW and OW were significantly lower than those in YW ($P<0.05$). Serum osteocalcin in MW and OW were significantly higher than those in YW ($P<0.05$). Handgrip strength in OW was significantly lower than that in YW and MW ($P<0.05$). Leg extension power in MW and OW were significantly lower than those in YW ($P<0.05$). *V*O$_2$peak (normalized to body mass) in MW and OW were significantly lower than those in YW ($P<0.05$).

Age-related decline of body composition and bone mineral indices

Leg SM mass and LSTM in MW and OW were significantly lower than those in YW ($P<0.05$, Table 2). Leg SM mass in OW was significantly lower than that in MW ($P<0.05$), but there was no such difference in leg LSTM. Table 3 shows the mean BMC, BMD and bone mineral indices normalized to SM mass. The BMC and BMD in MW and OW were significantly lower than those in YW ($P<0.05$), while BMC (whole body, arms, trunk and legs) and BMD (whole body, arms and legs) in OW were significantly lower than in those MW ($P<0.05$). The BMC normalized to SM mass in MW and OW was significantly lower than that in YW ($P<0.05$). The arm BMC normalized to arm SM mass and the trunk BMC normalized to trunk SM mass in OW were significantly lower than those in MW. However, whole-body and leg BMC normalized to leg SM mass were not significantly different between MW and OW. Furthermore, the interaction (age × BMI) of the age-related differences of BMD, BMC and normalized BMC was not significant.

There was significantly negative correlation between age and BMC normalized to SM mass in all women ($P<0.001$, Table 4). However, when the subjects were divided into three age groups, there was no significant correlation between age and BMC normalized to SM mass in middle-aged and older women.

Table 2 Skeletal muscle mass estimated by ultrasound and LSTM and fat mass measured by DXA

Variables	*Body segments*	*Young (n = 61)*	*Middle (n = 49)*	*Old (n = 28)*
SM mass (kg)	Whole body	14.3 ± 0.3	13.7 ± 0.3	12.0 ± 0.4^{a,b}
	Arm	1.4 ± 0.0	1.4 ± 0.0	1.3 ± 0.0^{a,b}
	Trunk	6.0 ± 0.0	5.8 ± 0.1	5.5 ± 0.1^{a,b}
	Leg	7.3 ± 0.1	6.9 ± 0.1^{a}	6.1 ± 0.2^{a,b}
LSTM (kg)	Whole body	34.3 ± 0.5	34.1 ± 0.5	32.4 ± 0.6^{a,b}
	Arm	3.2 ± 0.1	3.2 ± 0.1	3.1 ± 0.1
	Trunk	18.4 ± 0.2	18.8 ± 0.3	17.8 ± 0.3^{b}
	Leg	12.8 ± 0.2	12.1 ± 0.2^{a}	11.6 ± 0.3^{a}
Fat mass (kg)	Whole body	12.8 ± 0.4	17.4 ± 0.7^{a}	16.0 ± 0.6^{a,b}
	Arm	1.5 ± 0.1	2.0 ± 0.1^{a}	1.8 ± 0.1^{a}
	Trunk	4.8 ± 0.2	9.0 ± 0.4^{a}	8.1 ± 0.4^{a,b}
	Leg	6.2 ± 0.2	6.3 ± 0.2	5.8 ± 0.2

Abbreviations: DXA, dual-energy X-ray absorptiometry; LSTM, lean soft tissue mass; SM mass, skeletal muscle mass.
Data are presented as means ± s.e.m.
[a] Significantly different from young, $P<0.05$.
[b] Significantly different from middle-aged, $P<0.05$.

Relationships between SM mass, muscle functions and bone mineral indices

Lean soft tissue mass was significantly correlated with site-matched BMC (arm, trunk, leg and whole body; $r=0.57$, 0.73, 0.53 and 0.47, respectively; $P<0.05$, Figure 1) and BMD (arm, L-spine, leg and whole body; $r=0.38$, 0.40, 0.60 and 0.42, respectively; $P<0.05$, Figure 2). These associations corresponded to the relationships between SM mass measured by ultrasound and the site-matched BMC (arm, trunk, leg and whole body; $r=0.53$, 0.49, 0.66 and 0.55, respectively; $P<0.05$, Figure 1) and BMD (arm, L-spine, leg and whole body; $r=0.38$, 0.44, 0.55 and 0.52, respectively; $P<0.05$, Figure 2) in all women. The BMD in YW, MW and OW is also significantly correlated with the site-matched SM mass; $r=0.29$–0.54, 0.36–0.44 and 0.46–0.60, respectively ($P<0.05$). The correlation coefficients in OW were comparatively higher than those in YW or MW. In older women, absolute VO_2peak ($\mathrm{l\,min^{-1}}$) was not significantly correlated with whole-body BMD (Table 5). Moreover, the absolute leg extension power (W) and leg extension power normalized to body mass ($\mathrm{W\,kg^{-1}}$) were significantly correlated with leg BMD, but not leg extension power normalized to leg SM mass ($\mathrm{W\,kg^{-1}}$).

Discussion

This study investigated the relationships between regional SM mass and bone mineral indices, and sought to determine whether regional BMC normalized to SM mass showed a similar decrease with age in young subjects through old age.

Table 3 Age-related differences of bone mineral density, bone mineral and bone mineral content normalized to SM mass

Variables	*Body segments*	*Young (n = 61)*	*Middle (n = 49)*	*Old (n = 28)*
BMD (g cm ^{2})	Whole body	1.12 ± 0.01	0.99 ± 0.01^{a} (12%)	0.91 ± 0.01^{a,b} (8%)
	Arm	0.71 ± 0.01	0.63 ± 0.01^{a} (11%)	0.59 ± 0.01^{a,b} (6%)
	L-spine	1.07 ± 0.02	0.92 ± 0.02^{a} (14%)	0.86 ± 0.03^{a} (7%)
	Leg	1.12 ± 0.01	1.01 ± 0.01^{a} (10%)	0.94 ± 0.02^{a,b} (7%)
BMC (g)	Whole body	1796 ± 47	1350 ± 42^{a} (25%)	1175 ± 39^{a,b} (13%)
	Arm	238 ± 4	199 ± 5^{a} (16%)	174 ± 5^{a,b} (13%)
	Trunk	551 ± 12	451 ± 12^{a} (18%)	388 ± 11^{a,b} (14%)
	Leg	741 ± 14	600 ± 15^{a} (19%)	544 ± 16^{a,b} (9%)
BMC normalized to SM mass (g kg ^{1})	Whole body	127 ± 3	99 ± 2^{a} (22%)	100 ± 4^{a} (−1%)
	Arm	175 ± 2	144 ± 3^{a} (18%)	134 ± 3^{a,b} (7%)
	Trunk	93 ± 2	78 ± 2^{a} (16%)	71 ± 2^{a,b} (9%)
	Leg	102 ± 2	87 ± 2^{a} (15%)	91 ± 2^{a} (−5%)

Abbreviations: BMC, bone mineral content; BMD, bone mineral density; SM mass, skeletal muscle mass.
The percentage of differences were calculated from the value from young versus middle-aged and middle-aged versus old. Data are presented as means ± s.e.m.
[a] Significantly different from young, $P<0.05$.
[b] Significantly different from middle-aged, $P<0.05$.

Table 4 Correlation coefficients between age and measurement variables in young and postmenopausal women

Variables	*Body segments*	*Total (n = 138)*	*Young (n = 61)*	*Middle (n = 49)*	*Old (n = 28)*
BMD (g cm ^{2})	Whole body	−0.73***	0.00	−0.30*	−0.52***
	Arm	−0.75***	0.13	−0.24	−0.56***
	L-spine	−0.53***	0.04	−0.28	−0.40***
	Leg	−0.64***	0.01	−0.11	−0.39***
BMC (g)	Whole body	−0.67***	−0.40***	−0.16	−0.32
	Arm	−0.66***	0.13	−0.26	−0.54***
	Trunk	−0.64***	−0.05	−0.26	−0.24
	Leg	−0.63***	0.11	−0.13	−0.42***
LSTM (kg)	Whole body	−0.16	−0.02	−0.02	−0.25
	Arm	−0.07	−0.05	0.02	−0.27
	Trunk	−0.04	0.02	−0.09	−0.27
	Leg	−0.29**	−0.03	0.06	−0.17
SM mass (kg)	Whole body	−0.35***	0.03	−0.08	−0.44***
	Arm	−0.09	0.16	−0.13	−0.55***
	Trunk	−0.32***	−0.24	−0.20	−0.35
	Leg	−0.34***	−0.02	0.00	−0.23
BMC normalized to SM mass (g kg ^{1})	Whole body	−0.55***	−0.45***	−0.12	0.08
	Arm	−0.70***	−0.01	−0.20	−0.09
	Trunk	−0.55***	0.13	−0.14	0.02
	Leg	−0.41***	0.07	−0.12	−0.15

Abbreviations: BMC, bone mineral content; BMD, bone mineral density; LSTM, lean soft tissue mass; SM mass, skeletal muscle mass.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

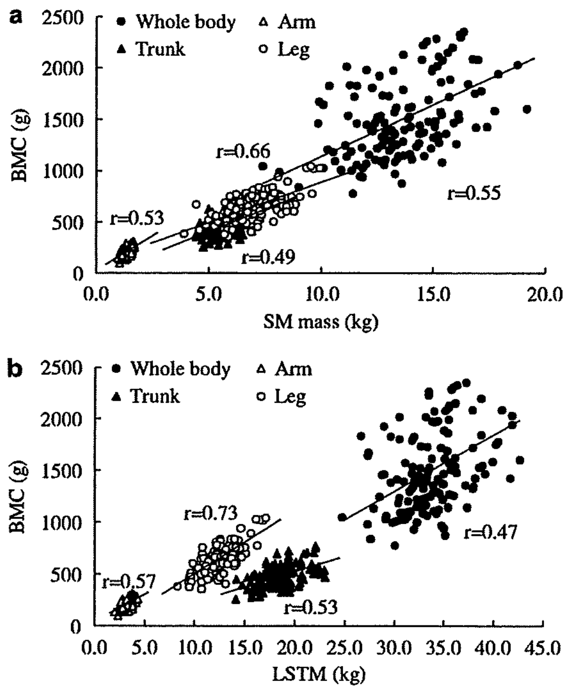

Figure 1 Relationship between SM mass estimated by ultrasound (**a**) or LSTM (**b**) measured by DXA and BMC in all subjects ($n = 138$). Whole-body and regional SM mass and LSTM were significantly correlated with BMC in all body segments ($P<0.05$). BMC, bone mineral content; DXA, dual-energy X-ray absorptiometry; LSTM, lean soft tissue mass; SM mass, skeletal muscle mass.

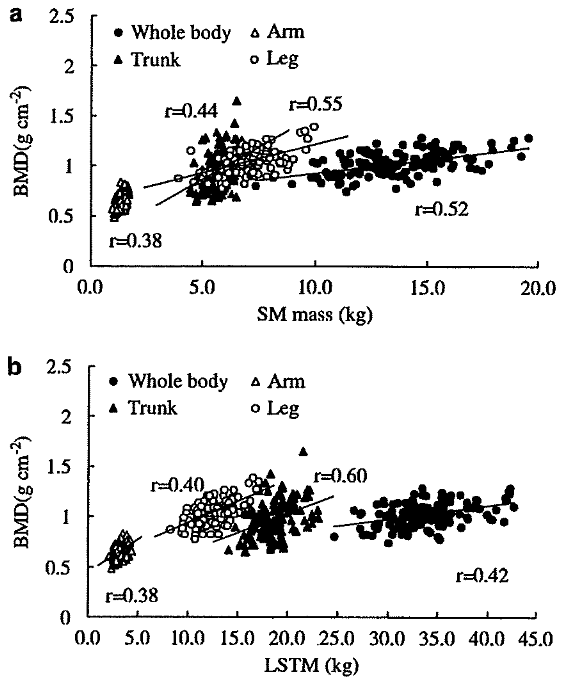

Figure 2 Relationship between SM mass estimated by ultrasound (**a**) or LSTM (**b**) measured by DXA and BMD in all subjects ($n = 138$). Whole-body and regional SM mass and LSTM were significantly correlated with BMD in all body segments ($P<0.05$). BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; LSTM, lean soft tissue mass; SM mass, skeletal muscle mass.

Table 5 Correlation coefficients between fitness value and BMD in young and postmenopausal women

	VO_2peak versus whole-body BMD			*Handgrip strength versus arm BMD*			*Leg extension power versus leg BMD*		
	Absolute ($l\,min^{-1}$)	*Normalized to body mass ($ml\,kg^{-1}\,min^{-1}$)*	*Normalized to total SM mass ($ml\,kg^{-1}\,min^{-1}$)*	*Absolute (kg)*	*Normalized to body mass ($kg\,kg^{-1}$)*	*Normalized to arm SM mass ($kg\,kg^{-1}$)*	*Absolute (W)*	*Normalized to body mass ($W\,kg^{-1}$)*	*Normalized to leg SM mass ($W\,kg^{-1}$)*
Young ($n=61$)	0.43***	0.30*	0.08	0.47***	0.37**	0.20	0.61***	0.49***	0.41***
Middle ($n=49$)	0.47***	0.17	0.09	0.34*	0.14	0.05	0.26	0.06	0.09
Old ($n=28$)	0.32	0.02	−0.18	0.42*	0.15	0.01	0.60***	0.46*	0.37

Abbreviations: BMD, bone mineral density; SM mass, skeletal muscle mass.
*$P<0.05$; **$P<0.01$; ***$P<0.001$.

The major findings of this cross-sectional study were as follows: (1) SM mass were associated with the site-matched bone mineral indices, and these associations corresponded to the relationships between LSTM and the site-matched bone mineral indices; (2) BMC normalized to SM mass estimated by ultrasound in arm and trunk region were also significantly different with age, but not in leg and whole body in middle-aged and older postmenopausal women. These results suggest that the age-related decline of BMC normalized to SM mass was different in the body segments. Thus, the age-related differences in BMC were found to be independent of the ageing of SM mass in the arm and trunk region. However, differences in BMC measures of the leg and whole body were found to correspond to age-related decline of SM mass in postmenopausal women.

Age-related decline in SM mass and bone mineral indices

As both SM mass and bone mineral indices decrease with age, it is not yet clear how the age-related decrease in SM mass (for example, arm, leg and trunk region) affects the age-related decline of bone mineral indices in young and postmenopausal women. The age-related differences in BMC normalized to the site-matched SM mass in MW were significantly lower than those in YW (15–22%, Table 3), and serum estradiol in MW were also significantly lower than those in YW (87%, $P<0.05$, Table 1). In addition, serum estradiol in MW was significantly lower than that in YW. These results suggest that age-related decrease of BMC from youth through middle age was associated with age-related change of oestrogen deficiency (NIH Consensus Development Panel on Osteoporosis Prevention, 2001). However, when postmenopausal women were divided into MW and OW, age-related differences in whole-body and leg BMC normalized to SM mass were absent in older postmenopausal women (Table 3) with no changes in serum estradiol and osteocalcin. Furthermore, the interaction (age × BMI) of the age-related differences of BMD, BMC and normalized BMC was not significant. Therefore, the age-related differences in whole-body and leg BMC among middle-aged and older postmenopausal women were considered partly due to the age-related changes in SM mass independent of the differences of BMI. These results support that the preservation of ageing of muscles is an important factor for maintenance of leg and whole-body BMC, especially in older women.

Relationships between SM mass, muscle function and bone mineral indices

The SM mass were associated with the site-matched bone mineral indices, and these associations show equivalent to better correlations among LSTM determined by DXA and the site-matched bone mineral indices. The final outcome is so much stronger when adjusted data use independent measurements. Every DXA-derived component from BMC to FM to LSTM is likely to co-vary, since they are all derived from the same scan. These results can be applied to the future studies such as the development of prediction equation for bone mineral indices using ultrasound technique. A compact-type ultrasound machine weighs approximately 3 kg, making it easily portable. Ultrasound-derived prediction equations are capable of taking measurements in the field, and are safe and valid in predicting total and regional SM mass (Sanada *et al.*, 2006).

Some investigators have shown that prolonged low-to-moderate intensity exercise is independently associated with higher BMD (Nguyen *et al.*, 1998; Hagberg *et al.*, 2001; Pongchaiyakul *et al.*, 2004), while cardiorespiratory fitness (VO_2peak) is only slightly correlated with bone mineral indices (Henderson *et al.*, 1995; Ryan and Elahi, 1998; Ryan *et al.*, 1998; Lynch *et al.*, 2002). In this study, VO_2peak (normalized to body mass) in young women was significantly correlated with BMD ($P<0.05$), while VO_2peak (normalized to whole-body SM mass) was not significantly associated with BMD (Table 5). These results indicate that although the present and previous studies have shown aerobic fitness to be associated with BMD, this relationship may be due to the magnitude of SM mass. However, in older women, even absolute VO_2peak ($l\,min^{-1}$) was not significantly correlated with whole-body BMD. In the same way, low grip strength is associated with low BMD and an increased risk of incident vertebral fracture (Bevier *et al.*, 1989; Osei-Hyiaman *et al.*, 1999; Di Monaco *et al.*, 2000; Dixon *et al.*, 2005). The absolute handgrip strength in older women were significantly correlated with BMD, but not normalized to body mass and SM mass, in present study. These results suggest the relation of BMD and handgrip strength associated with body mass. However, the absolute leg extension power (W) and leg extension power normalized to body mass ($\mathrm{W\,kg^{-1}}$) were significantly correlated with leg BMD, but not normalized to leg SM mass ($\mathrm{W\,kg^{-1}}$). There is no difference in leg BMC (normalized to SM) between middle-aged and older women, there may be a difference but this study does not have the power to demonstrate a difference, particularly as the numbers are much less in the older groups.

Summary

We assessed the relationship between regional SM mass and bone mineral indices, and whether BMC normalized to site-matched SM mass differed with age. This cross-sectional study concluded that whole-body and regional SM mass are associated with site-matched BMD and BMC in both young and postmenopausal women. Moreover, the age-related differences in BMC were found to be independent of the ageing of SM mass in the arm and trunk region. However, differences in BMC measures of the leg and whole body were found to correspond to age-related decline of SM mass in postmenopausal women. These results support that the preservation of ageing of SM mass is an important factor for maintenance of leg and whole-body BMC especially in older women.

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ORIGINAL ARTICLE

Resting energy expenditure can be assessed by dual-energy X-ray absorptiometry in women regardless of age and fitness

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Objective: To evaluate the possibility that measurement of the magnitude and distribution of fundamental somatic heat-producing units using dual-energy X-ray absorptiometry (DXA) can be used to estimate resting energy expenditure (REE) in both young and elderly women with different aerobic fitness levels.

Subjects and methods: Peak oxygen uptake (VO_2 peak) and REE_m were directly measured in 116 young (age: 22.3 ± 2.1 years) and 72 elderly (63.3 ± 6.4 years) women. The subjects were divided into four groups according to categories of age and VO_2 peak; young: high fitness (YH, $n=58$); low fitness (YL, $n=58$); elderly: high fitness (EH, $n=37$) and low fitness (EL, $n=35$). Using DXA, systemic and regional body compositions were measured, and REE_e was estimated from the sum of tissue organ weights multiplied by corresponding metabolic rate.

Results: Although there were remarkable differences in systemic and regional body compositions, no significant differences were observed between REE_m and REE_e in the four groups. REE_e significantly correlated with REE_m in elderly as well as young women; the slopes and intercepts of the two regression lines were statistically not different between the elderly and young groups (elderly: $y=0.60x+472$, $r=0.667$; young: $y=0.78x+250$, $r=0.798$; $P<0.001$, respectively). A Bland–Altman analysis did not indicate bias in calculation of REE for all the subjects.

Conclusion: These results suggest that REE can be estimated from tissue organ components in women regardless of age and aerobic fitness.

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Introduction

Resting energy expenditure (REE) accounts for 60–80% of total daily energy expenditure and is the basis for estimating the energy requirement. In the field of energy metabolism, early investigators showed intense interest in establishing the determinant factors of REE (Cunningham, 1980, 1991; Nelson *et al.*, 1992). To date, some earlier studies demonstrated that body mass, especially fat-free mass (FFM), has been a useful candidate in estimating REE (Ravussin and Bogardus, 1989; Fukagawa *et al.*, 1990; Tataranni and Ravussin, 1995).

Changes in body weight (BW) including fat mass (FM) and FFM may be caused by various factors, such as biological aging, decreasing physical activity levels, nutritional status and health condition. Particularly in women, the menopause is also associated with increased body mass accompanied by elevated adiposity (Fukagawa *et al.*, 1990; Svendsen *et al.*, 1995; Guo *et al.*, 1999). Svendsen *et al.* (1995) have noted that postmenopausal women had significantly larger amounts of fat deposition, a higher abdominal fat distribution and lower lean tissue mass, including skeletal muscle, bone and intestinal organs than premenopausal women.

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Very little is known as to whether aerobically higher fitness individuals have higher metabolic rates in resting state. Ravussin and Bogardus (1989) reported that maximal O_2 uptake was not related to resting metabolic rate in non-diabetic, non-trained Pima Indians. However, they demonstrated that resting metabolic rate was significantly higher in well-trained men, when compared with sedentary men matched for BW, FFM and age (Ravussin and Bogardus, 1989). Thus, the question whether aerobic fitness level relates to REE remains unanswered.

Dual-energy X-ray absorptiometry (DXA) can easily and accurately assess the body composition, including bone mineral content (BMC), FM and FFM of the whole body and segments. Recently, Hayes *et al.* (2002) demonstrated that REE can be estimated from the summed heat productions from the weights of the brain, skeletal muscle mass (SM), adipose tissue (AT), bone and tissue organs by DXA. In view of the finding of Hayes *et al.* (2002), we decided to evaluate the possibility that measurement of the magnitude and distribution of fundamental somatic heat-producing units using DXA can be used to estimate REE in both young and elderly women with different aerobic fitness levels.

Materials and methods

Subjects

In total, 127 young women (age: 22.4 ± 2.2 years) and 83 elderly women (61.7 ± 8.1 years) were recruited for the study. Subjects who had too low and high body mass index (BMI <18.5 and BMI $>30\,\mathrm{kg\,m^{-2}}$) and had used medications that affect bone and estrogen replacement were eliminated from the analysis. Hence, 116 healthy young women (22.3 ± 2.1 years) and 72 healthy elderly women (63.3 ± 6.4 years) who had passed three years or more (13.5 ± 7.4 years) after menopause were selected for this study. The subjects were divided into four groups according to their aerobic fitness levels relative to BW (VO_2 peak: $\mathrm{ml\,kg^{-1}\,min^{-1}}$), and the median of VO_2 peak for each age, which were 36.4 (20–29 years), 27.1 (50–59 years), 25.8 (60–69 years) and 21.0 (70–79 years) $\mathrm{ml\,kg^{-1}\,min^{-1}}$ [young high fitness (YH): $n = 58$; young low fitness (YL): $n = 58$; elderly high fitness (EH): $n = 37$ and elderly low fitness (EL): $n = 35$]. All subjects were informed about the purpose and possible risks of the study and were then provided written informed consent, as approved by the Ethical Committee at the National Institute of Health and Nutrition in Japan.

Study protocol and direct measurement of REE

Participants came to the National Institute of Health and Nutrition in the morning. Subjects were asked to minimize any walking while en route from their home to the laboratory before REE determination. The subjects were restricted to perform any other exercises at least 24 h prior to the testing. The measured REEs (REE_m) was directly measured by open-circuit indirect calorimetry. Measurements were performed between 0700 and 0900 h after 10–12 h of fasting, except water, in a room at constant room temperature (23–25 °C). After entering the laboratory, subjects rested in the supine position for at least 30 min, and a Hans-Rudolph full face mask (Hans Rudolph Inc., Kansas City, MO, USA) was put on. Two samples of expired air were collected in Douglas bags for a duration of 10 min each, and the mean value was used for the analysis. For young subjects, all measurements were made during the follicular phase of the menstrual cycle.

An oxygen and carbon dioxide analyzer (Arco-1000A; Arco system, Japan) was used to analyze the rate of oxygen consumption and carbon dioxide production. The volume of expired air was determined using a dry gas volume meter (DC-5; Shinagawa, Japan) and converted to standard temperature, standard pressure and dry gas. Gas exchange results were converted to REE ($\mathrm{kcal\,day^{-1}}$) using Weir's equation (Weir, 1949).

Body composition analysis

Anthropometric measurements. BW was measured to the nearest 0.1 kg by using an electronic scale (Inner Scan BC-600; Tanita Co., Japan), and height was measured to the nearest 0.1 cm by using a stadiometer (YL-65; Yagami Inc., Japan). BW and height were measured with subjects wearing light clothing and no shoes. BMI was calculated by dividing BW in kilograms by the square of height in meters ($\mathrm{kg\,m^{-2}}$).

DXA. The percentage of fat (% body fat) and BMC of the whole body and appendicular lean soft tissue (LST) were measured by DXA (Hologic QDR-4500 DXA Scanner; Hologic Inc., Whaltham, MA, USA). Manufacturer's software version 11.2 for Windows was used to analyze the % body fat, BMC and LST. FFM and FM were calculated by BW and % body fat.

Test of aerobic capacity (VO_2 peak)

Young subjects were habituated to pedaling a dynamically calibrated Monark Model 828E cycle ergometer (Monark Exercise AB, Varberg, Sweden). On the other hand, aerobic capacity in elderly subjects was assessed by a progressive continuous test to exhaustion on a motor-driven treadmill with walking and running. All subjects wore a Hans-Rudolph full face mask. Oxygen consumption and carbon dioxide production of all subjects were measured during the last 30 s of each stage and analyzed using an oxygen and carbon dioxide analyzer. Heart rate was monitored electrocardiographically during the last 15 s of each minute, and a 'steady state' was regarded to have occurred if consecutive readings differed by <3 $\mathrm{beats\,min^{-1}}$. Four criteria were used to determine a successful maximal test: (1) a leveling or plateauing of VO_2 (defined as an increase in oxygen uptake $<2\,\mathrm{ml\,kg^{-1}\,min^{-1}}$); (2) maximal heart rate >195 or (220–age); (3) respiratory exchange ratio $\geqslant 1.0$ and (4) rating of perceived exertion ⩾18 (Johnson *et al.*, 2000; Santa-Clara *et al.*, 2006). VO_2 peak was defined by the attainment of at least two of the four criteria.

Calculation of tissue organ mass and estimation of REE

Tissue organ mass was calculated using the previously reported prediction model as follows.

Bone mass (BM) was calculated by multiplying BMC times 1.85 (Snyder *et al.*, 1975; Heymsfield *et al.*, 1990). AT was assumed to be 85% fat (Heymsfield *et al.*, 2002), leading to the model based on FM. Thus, AT was calculated by multiplying FM times 1.18. SM was calculated using the prediction model of Kim *et al.* (2002) ($R^2 = 0.96$; SEE = 1.58 kg; $P < 0.001$). Finally, residual mass (RM) was calculated as the difference between BW and the sum of the calculated BM, AT and SM.

BM (kg) = BMC (g) × 1.85/1000
AT (kg) = FM (kg) × 1.18
SM (kg) = 1.13 × LST (kg) − 0.02 × age (years) + 0.97
RM (kg) = BW − (BM + AT + SM)

Estimation of REE (REE_e) was based on the sum of four body compartments (BM, AT, SM and RM) times the corresponding tissue respiration rate as follows. The specific resting metabolic rate of the four compartments was assumed from previously reported data, bone (2.3 kcal kg^{-1}), AT (4.5 kcal kg^{-1}), skeletal muscle (13 kcal kg^{-1}) and residual (53 kcal kg^{-1}) (Holliday *et al.*, 1967; Grande, 1989; Elia, 1992; Hayes *et al.*, 2002; Heymsfield *et al.*, 2002).

$$REE_e = 2.3BM + 4.5AT + 13SM + 53RM$$

Statistical analysis

The data were presented as mean ± s.d. Statistical analyses were carried out with the Sigma Stat 2.03 (Systat Software Inc., CA, USA). A two-way analysis of variance was used to test for interaction effects between the age and aerobic fitness levels among the mean values for the four groups. Where appropriate, the *Tukey* test was employed to locate the source of the significant differences. To determine the associations between measured and estimated REE, Bland–Altman plots were used (Bland and Altman, 1986). For all the statistical analyses, the level of significance was defined as less than 0.05.

Results

Table 1 presents the comparisons of characteristics, composition of whole body and aerobic fitness levels. BW and FFM were significantly higher in the YH group than in the YL group and EH group. The % body fat tended to be higher in the EL group compared with the other groups, but this interaction between age and aerobic fitness level was just short of statistical significance (age: $P < 0.001$; aerobic fitness level: $P < 0.001$; interaction: $P = 0.056$). However, no significant interaction in BMI and FM was noted in the four groups.

REE_m in the YH group was ~15% higher than in the other three groups (Table 2).

Table 2 Measured and estimated resting energy expenditure

	Young		*Elderly*	
	YH (n = *58)*	*YL* (n = *58)*	*EH* (n = *37)*	*EL* (n = *35)*
REE_m	1265 ± 155	1118 ± 114^a	1080 ± 125^b	1093 ± 92
REE_e	1246 ± 161	1108 ± 101^a	1128 ± 108^a	1128 ± 89
$REE_m - REE_e$	19 ± 105	9 ± 89	−48 ± 92	−35 ± 79

Abbreviations: REE_m, measured by expiratory gas exchange; REE_e, estimated by four tissue organs.
Values are means ± s.d., kcal day^{-1}.
$REE_e = 13SM + 2.3BM + 4.5AT + 54RM$, significance was determined by two-way analysis of variance (ANOVA).
$^a P < 0.05$ vs high-fitness group (same age group).
$^b P < 0.05$ vs young group (same fitness category).

Table 1 Subject characteristics for the healthy female adults

	Young		*Elderly*	
	YH (n = 58)	*YL* (n = *58)*	*EH* (n = *37)*	*EL* (n = *35)*
Age (years)	21.8 ± 1.9	22.8 ± 2.2	62.4 ± 6.7	64.3 ± 6.1
Ht (cm)	163.2 ± 6.6	159.5 ± 6.3^a	153.1 ± 5.4^b	154.7 ± 5.0^b
BW (kg)	57.1 ± 6.8	53.9 ± 5.9^a	53.2 ± 6.0^b	55.5 ± 5.9
BMI (kg m ^{2})	21.4 ± 1.9	21.2 ± 1.9	22.7 ± 2.1	23.2 ± 2.5
FFM (kg)	44.7 ± 5.6	39.5 ± 4.0^a	37.6 ± 3.7^b	37.9 ± 3.3
FM (kg)	12.3 ± 2.6	14.3 ± 3.0	15.5 ± 3.6	17.7 ± 4.1
% body fat	21.6 ± 3.6	26.5 ± 3.6	29.0 ± 4.5	31.5 ± 4.8
VO_2 peak (ml kg ^{1} min ^{1})	42.3 ± 4.8	32.1 ± 2.9^a	29.8 ± 4.2^b	22.2 ± 2.8^{a,b}

Abbreviations: BMI, body mass index; BW, body weight; FFM, fat-free mass; FM, fat mass; Ht, height.
Values are means ± s.d.
Significance was determined by two-way analysis of variance (ANOVA).
$^a P < 0.05$ vs high-fitness group (same age group).
$^b P < 0.05$ vs young group (same fitness category).

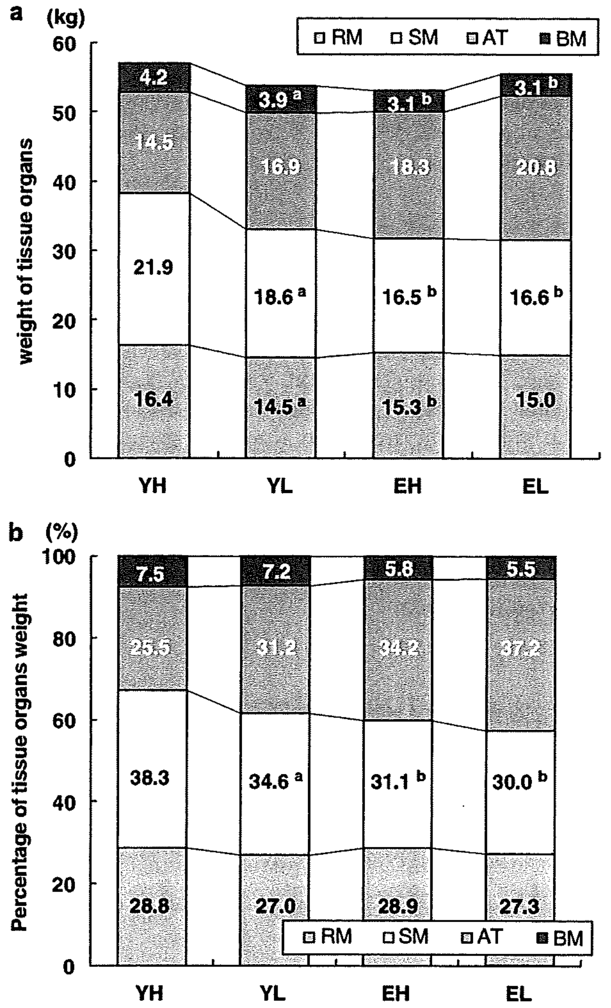

Figure 1 Four tissue organ components in women expressed as a weight (a) and as their respective fractional contributions to body weight (b). RM, residual mass; SM, skeletal muscle; AT, adipose tissue; BM, bone mass. Significance was determined by two-way analysis of variance (ANOVA). $^aP<0.05$ vs high-fitness group (same age group) and $^bP<0.05$ vs young group (same fitness category).

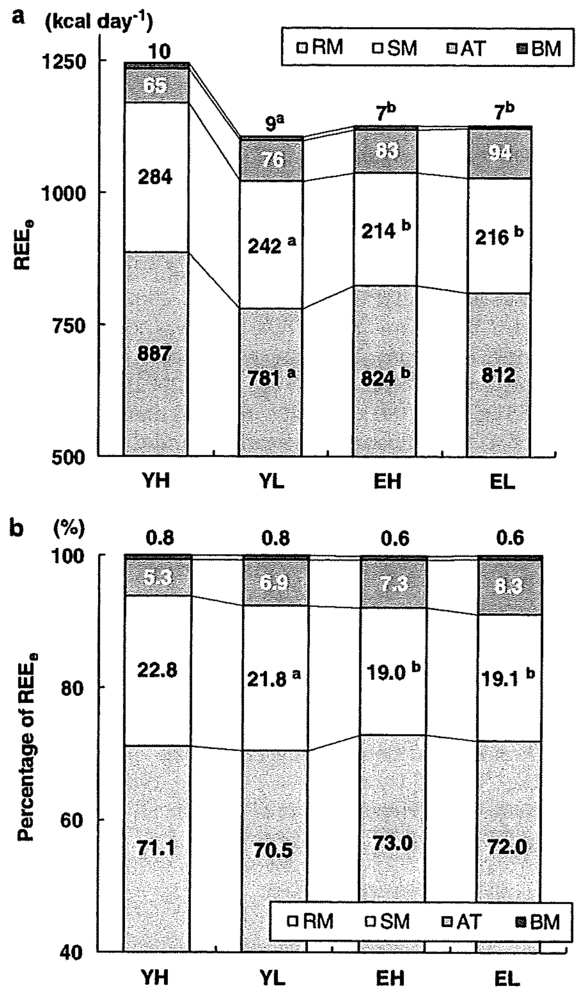

Figure 2 Four tissue organ components in women expressed as a specific energy expenditure (a) and as their respective fractional contributions to REE_e (b). RM, residual mass; SM, skeletal muscle; AT, adipose tissue; BM, bone mass; REE_e, resting energy expenditure estimated by four tissue organs. $REE_e = 13SM + 2.3BM + 4.5AT + 54RM$. Significance was determined by two-way analysis of variance (ANOVA). $^aP<0.05$ vs high-fitness group (same age group) and $^bP<0.05$ vs young group (same fitness category).

The absolute and relative values of the weight of the four tissue organs are presented in Figures 1a and b, respectively. SM and BM in YH were significantly higher than in YL, and were also significantly higher in young women than in elderly women of the same fitness category. The absolute value of RM was also significantly higher in YH than in YL and EH. However, no significant interaction in AT was noted among the four groups. When these four tissue masses were expressed as a percentage of BW, SM in YH was significantly higher than in YL, and was also significantly higher in young women than in elderly women of the same fitness category. This result was similar to that for SM mass. The relative mass of AT in EL tended to be higher than in the respective group, whereas no statistical significance in this interaction between age and aerobic fitness levels was observed.

Figures 2a and b present the absolute and relative values of the energy expenditure of the four different tissue organs. Our data noted significant differences in only SM as a percentage of the energy expenditure in the four groups. Specifically, the energy expenditure of SM as a percentage of the whole body in elderly women was lower than in the same fitness category (percentage energy expenditure of RM, AT and BM did not differ among the groups).

Tissue organ-derived REE_e was significantly higher in the YH than in the YL and EH groups (Table 2). There was also no

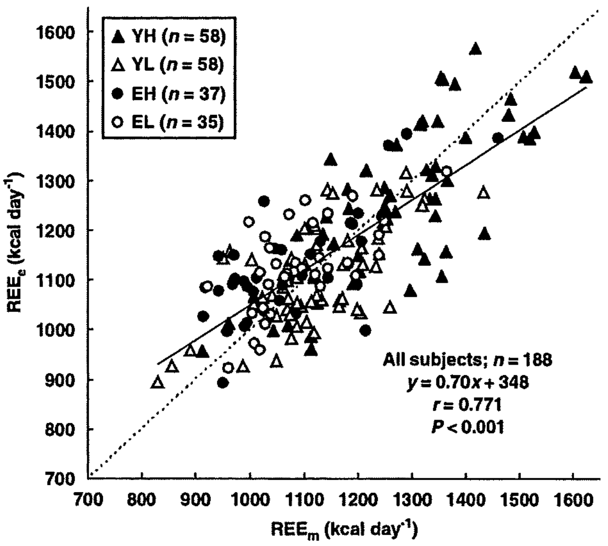

Figure 3 Relationship between the measured and estimated resting energy expenditure. REE$_m$, measured by expiratory gas exchange; REE$_e$, estimated by four tissue organs. $REE_e = 13SM + 2.3BM + 4.5AT + 54RM$.

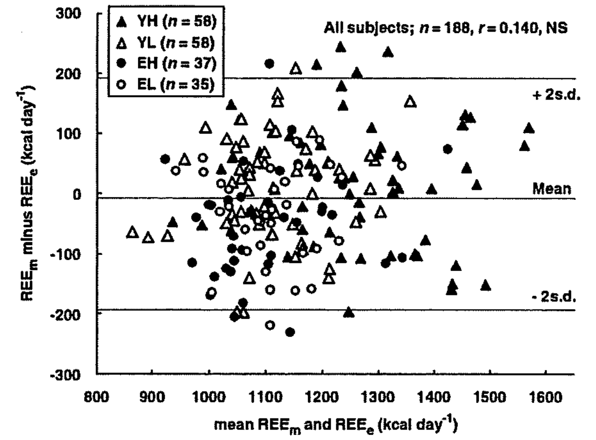

Figure 4 Bland–Altman analysis. Plots of the differences between REE$_m$ and REE$_e$. REE$_m$, measured by expiratory gas exchange; REE$_e$, estimated by four tissue organs. $REE_e = 13SM + 2.3BM + 4.5AT + 54RM$.

significant difference between REE$_m$ and REE$_e$ in the four groups. In addition, a significant relationship between REE$_m$ and REE$_e$ was observed in all subjects (Figure 3). A Bland–Altman analysis did not indicate any bias in the calculation of REE for all subjects (Figure 4).

Discussion

The major finding from the present study is that REE in adult women can be accurately estimated from tissue organ components by using DXA regardless of age and aerobic fitness levels.

Measured and estimated REEs

A strongly significant relationship between REE$_m$ and REE$_e$ was observed in all subjects ($r = 0.771$, $P < 0.001$; Figure 3) and a Bland–Altman analysis did not indicate bias in the estimation of REE (all subjects: $r = 0.140$; young: $r = 0.041$; elderly: $r = 0.133$, NS, respectively; Figure 4). Furthermore, our study indicated that REE$_e$ was related significantly to REE$_m$ in both young and elderly women (elderly: $y = 0.60x + 472$, $r = 0.667$; young: $y = 0.78x + 250$, $r = 0.798$; $P < 0.001$ for both), and the slopes and intercepts of the two regression lines were statistically not different between the young and elderly groups (slopes: $t = 1.652$; intercept: $t = 1.881$; NS for both). This suggests the possibility that the difference in the ratio of SM and RM to FFM is important rather than the decline in the specific metabolic rate with advancing age.

It is well known that REE decreases after menopause in women, potentially contributing to changes in body composition (Vaughan *et al.*, 1991; Hunter *et al.*, 2001). It is unclear, however, whether the decrease in REE is a consequence of an age-dependent decrease in FFM, which includes skeletal muscle, bone and tissue organs. In the present study, the absolute REE$_m$s (kcal day^{-1}) are ~15% lower in the YL, EH and EL groups compared with the YH group (Table 2). When REE$_m$ is expressed in terms of FFM, however, no significant differences in absolute REE$_m$ were obtained among the groups (YH vs YL vs EH vs EL: 28.4 ± 2.3 vs 28.4 ± 2.3 vs 28.8 ± 2.7 vs 29.0 ± 2.1 kcal kg^{-1} day^{-1}). This result did not correspond to previous reports on sedentary adult women and men (Van Pelt *et al.*, 1997, 2001; Piers *et al.*, 1998). Van Pelt *et al.* (1997, 2001) and Piers *et al.* (1998) reported that the effect of age on REE was significantly negative in healthy sedentary adults, even after adjusting for age-related differences in body composition.

On the basis of the different tissue masses and their specific metabolic rates (Elia, 1992), Gallagher *et al.* (1998, 2000) examined the relationship between REE and body composition divided into numerous tissues and organs. In addition, Hayes *et al.* (2002) investigated whether the REE can be calculated from the summed heat productions from the weight of tissue organs estimated by DXA. Their study showed that no bias was detected between measured and predicted REEs (Hayes *et al.*, 2002).

Aerobic fitness level and body composition

Our present data showed that the aerobic fitness level in the elderly was ~30% lower than in young adults in both high- and low-fitness level groups. The reduction rate of VO_2 peak/BW was ~7.5% per decade of age. Earlier study showed a 7.5% reduction per decade in VO_2 max for 20–75 years of age (Pollock *et al.*, 1987).

In the present study, the % body fat in high fitness or young group was lower than in low fitness or elderly group of the same category, but this interaction between age and aerobic fitness level was just short of statistical significance ($P = 0.056$). On the other hand, FFM was significantly higher in YH than in the other three groups, and no significant differences in FFM were noted among the YL, EH and EL groups (Table 1). These findings are in accordance with earlier studies (Van Pelt *et al.*, 1997, 2001), suggesting that keeping aerobically fit can prevent an increase in % body fat with aging.

Our present study also focused on the weight or energy expenditure of DXA-estimated tissue organs, as a component of the whole body, to assess the relationship between FFM and REE_m. The percentage of AT mass suggested that keeping a high aerobic fitness level may suppress the age-related increase in total body fat. In contrast, SM decreases in elderly women regardless of their aerobic fitness levels (Figures 1a and b). These results suggested that, in elderly women, it could be difficult to prevent a decrease in the volume of skeletal muscle, by performing aerobic exercise, such as swimming, walking or jogging. Resistance exercise should be combined with aerobic exercise for elderly women.

Limitations

Our investigation has a few limitations. First, the weight of tissue organs could not be directly measured by using apparatus, such as a magnetic resonance imaging. Second, we did not observe directly the magnitude of the summed heat produced by the tissue organs. Third, we did not test middle-aged (30–49 years) adults. Future studies should widen the characteristics of the subjects to include lean and obese adults or middle-aged adults. Future studies are needed to extend these observations and to analyze gender-related, hormonal, ethnic and other determinant factors of REE.

In conclusion, the present investigation demonstrated that estimation of the four tissue organs by using DXA allows successful calculation of REE in female adults regardless of age and aerobic fitness levels. The findings suggest the possibility that REE is regulated mainly by the mass of the tissue organs with lower and higher metabolic rates, including skeletal muscle and intestinal organs, rather than a decline in the specific metabolic rate of different tissue organs associated with advancing age and decreasing aerobic fitness levels in young and elderly women.

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3分間歩行テストによる最大酸素摂取量推定式の開発に関する研究

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樋口　満[3)]　田畑　泉[1)]

DEVELOPMENT OF $\dot{V}O_{2max}$ PREDICTION MODELS FROM 3-MINUTE WALK TEST

ZHEN-BO CAO, NOBUYUKI MIYATAKE,
MITSURU HIGUCHI and IZUMI TABATA

Abstract

The purpose of the study was to develop new $\dot{V}O_{2max}$ prediction models for Japanese men using a 3-minute walk test. One hundred and twenty-seven Japanese men aged from 20 to 69 years were recruited as subjects of the present study. Maximal oxygen uptake ($\dot{V}O_{2max}$) was measured with a maximal incremental test on a bicycle ergometer. The prediction models were derived using data of age, 3-minute walking distance (3MWD), and either BMI, waist circumference (WC), or %Fat. This data was cross-validated by using PRESS cross-validation procedures. 3MWD was significantly related to $\dot{V}O_{2max}$ ($r = 0.54$, $P < 0.001$). The multiple correlation coefficients for the BMI, WC, and %Fat models, respectively, were 0.81, 0.82, and 0.85. The standard error of estimate (SEE) was 4.5, 4.4, and 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, for the BMI, WC, and %Fat models. All regression models demonstrated a high level of cross-validity supported by the minor shrinkage of the coefficient of determination and increment of SEE in the PRESS procedure. This study demonstrated that 3MWD was useful for predicting $\dot{V}O_{2max}$ accurately using $\dot{V}O_{2max}$ prediction models for Japanese men. The new non-exercise prediction equations derived in this study are applicable to estimating $\dot{V}O_{2max}$ in Japanese adult men.

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key word : Cardiorespiratory fitness, maximal oxygen uptake, prediction model, field test, male

Ⅰ．緒　言

全身持久力は，死亡，循環器疾患及びメタボリックシンドローム等の独立した危険因子であることが国内外の疫学研究により明らかにされている[1-5]．2006年７月，厚生労働省は生活習慣病の発症予防を目的とした「健康づくりのための運動基準2006」(EPAR2006)[6]を公表し，生活習慣病を予防するために全身持久力の指標である最大酸素摂取量（$\dot{V}O_{2max}$）を高い水準に維持することが重要であることを示した上で，生活習慣病発症予防に必要な$\dot{V}O_{2max}$の基準値と範囲を示した．

直接法による$\dot{V}O_{2max}$測定法が最も信頼性が高いが，多人数を安全に，安価に測定するには困難な場合が多い．このようなことを踏まえて，様々なフィールドテストが提案されている．日本でも，文部科学省は20mシャトルラン（20～64歳）と６分間歩行テスト（65歳以上）を全身持久力テストとして採用している．しかし，このようなテストでも，特定の測定器具や長い測定時間が必要であり，個人及び集団での測定が困難であり，経済性や安全性，簡便性のいずれの面からみても現場での使用が容易であるとはいえない．そこで，より多くの健康・運動指導の現場でより簡便に$\dot{V}O_{2max}$を利用して全身持久力を

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評価できるように，「健康づくりのための運動指針2006」（エクササイズガイド2006）[7]では，３分間歩行テスト（「ややきつい」と被験者自身が感じる速さでの３分間歩行距離）といった簡便な持久力評価テストを提案し，それから推定された$\dot{V}O_{2max}$と基準値との比較により持久力を評価するとした．しかし，この３分間歩行テストを用いた$\dot{V}O_{2max}$の推定法（エクササイズガイド2006）の交差妥当性を検討した研究はない．そこで，本研究では成人男性を対象としてこの３分間歩行テストを用いた$\dot{V}O_{2max}$の推定法の交差妥当性を検討し，さらに３分間歩行距離に年齢及び身体組成などの独立因子を加え，$\dot{V}O_{2max}$の新しい推定式の開発とその妥当性について検討した．

Ⅱ．方　　法

A．対象者

被験者は，20～69歳の健康的な男性127名であった．その年齢別の内訳は，20代が20名，30代が26名，40代が29名，50代が24名，60代が28名であった．すべての被験者は$\dot{V}O_{2max}$の評価に影響を与える慢性疾患を有していないもの（循環器疾患，がん，糖尿病，高脂血症，高血圧症，肥満症といった生活習慣病の発症歴がないもの）であった．被験者の１日の歩数の平均値は9047±3656歩であった．被験者の特性を【表１】に示した．本研究は，独立行政法人国立健康・栄養研究所倫理委員会の承認を得て，ヘルシンキ宣言の趣旨に則り行った．対象者には事前に本研究の趣旨や測定内容，測定時の危険性などに関する説明を行い，参加への承諾を書面で得た．

B．身体計測

各被験者の身長と体重を測定し，身長と体重よりBMI（Body mass index）を算出した．体脂肪率はインピーダンス法（BC-600，株式会社タニタ社製，N=54）あるいはDEXA法（Dual Energy X-ray Absorptiometry，N=82）（QDR4500A，Hologic社製）により測定した．また，布製のメジャーを使用し，臍位置での腹囲を測定した．

C．$\dot{V}O_{2max}$の測定

自転車エルゴメーター（Monark社製あるいはLode社製）を用いた漸増負荷法により，$\dot{V}O_{2max}$を測定した．ペダル回転数は60rpmとし，心拍数（HR）が110bpm前後になるような負荷で５分間ウォーミングアップを行わせた後，その負荷から測定を開始し，１分毎に15Wずつ負荷を増加させた．運動中，呼気ガス指標は呼吸代謝測定システム（ミナト医科学社製あるいはMijnhardt社製）を用いて，breath-by-breath法により酸素摂取量（$\dot{V}O_2$）と二酸化炭素排出量（$\dot{V}CO_2$）を測定し，30秒ごとの平均値に換算して出力したデータを$\dot{V}O_{2max}$の決定に用いた．全ての実験前に，校正用ガスでの濃度校正ならびに2Lあるいは3Lのシリンジを用いて熱線流量計の校正を行った．呼吸代謝測定システムの測定精度については，ダグラスバッグ法と高い妥当性が確認されている[8,9]．また，運動中は心拍数（HR）と心電図を心電計でモニタリングし，負荷を上げる毎に運動直後の主観的運動強度（RPE）を記録した．$\dot{V}O_{2max}$はCao et al.[10,11]の基準，すなわち，1）$\dot{V}O_2$のleveling-off，2）運動時HRの最大値が予測最大HR（220－暦年齢）の95%以上，の２つの判定基準を満たしていることを条件とした．

D．３分間歩行テスト

「エクササイズガイド2006」において持久力の評価法として採用されている３分間歩行は，体育館で20mの折り返し直線のコースを，主観的運動強度（(Ratings of Perceived Exertion (RPE))[12]が13「ややきつい」と被験者自身が感じる速さで３分間歩き，その距離を測定した．

E．統計処理

各測定項目の値は平均値±SDで表した．またPearson相関関係の検定を行った．エクササイズガイド2006の最大下歩行距離から最大酸素摂取量を推定する方法の交差妥当性を検討するため，予測$\dot{V}O_{2max}$は$\dot{V}O_{2max}$の実測値に対する直線関係（線性回帰）から，以下に示す標準推定誤差（SEE1，$= SDy\sqrt{1-r^2}$，SDy: 実測値の標準偏差；r：実測値と予測値の相関係数）と合計誤差（TE，$= \sqrt{(\Sigma(\text{measured } \dot{V}O_{2max} - \text{predicted } \dot{V}O_{2max})^2/n)}$）を算出した．階層線形回帰分析を用いて$\dot{V}O_{2max}$の新しい推定式を求めた．推定式の精度を検証するために，決定係数（R^2）と推定の標準誤差（SEE）を検証した．その後，この推定式はPRESS統計方法を

用いて交差妥当性を検証した[13]．使用した係数はPRESS決定係数（$R^2p, = 1-(\mathrm{PRESS}/\mathrm{SStotal})$）と推定の標準誤差（$\mathrm{SEEp}, = \sqrt{\mathrm{PRESS}/n}$）であった．有意水準は5％以下とした．

Ⅲ．結　果

A．被験者の特性

被験者のBMI，体脂肪率及び腹囲の平均値をTable 1に示した．年代別の3分間歩行距離（平均値±SD）は20代で393±61m，30代で377±55m，40代で346±45m，50代で364±48m，60代で350±45mであった（Table 2）．実測された年代別の体重当たりの$\dot{V}O_{2max}$の平均値は20代で45.2ml･kg^{-1}･min^{-1}，30代で41.0ml･kg^{-1}･min^{-1}，40代で34.9ml･kg^{-1}･min^{-1}，50代で34.5ml･kg^{-1}･min^{-1}，60代で30.3ml･kg^{-1}･min^{-1}であった（Table 2）．

B．$\dot{V}O_{2max}$，年齢，身体組成および3分間歩行距離の関係（Table 3）

$\dot{V}O_{2max}$は年齢及び身体組成との間に有意な負の相関関係が認められた．一方，$\dot{V}O_{2max}$は3分間歩行距離との間に有意な正の相関関係（$r=0.54$，$P<0.001$）が認められた（Figure 1）．3分間歩行距離は年齢及び身体組成との間に有意な負の相関関係（$r=-0.24$（年齢），$r=-0.23$（BMI），$r=-0.41$（体脂肪率），$r=-0.40$（腹囲），$P<0.001$）が認められた．

Table 1. Physical characteristics of the subjects

Variable	Mean ± SD
	N = 127
Age (yr)	45.4 ± 13.9
Height (cm)	170.4 ± 6.0
Body mass (kg)	67.8 ± 8.9
BMI (kg·m^{-2})	23.3 ± 2.8
%Fat (%)	20.0 ± 5.0
WC (cm)	82.5 ± 8.1
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	36.7 ± 7.6
3-minute walk distance (m)	364 ± 53

BMI, body mass index; WC, waist circumference; %Fat, body fat percentage.

Table 2. Reference and measured values of $\dot{V}O_{2max}$ and 3-minute walk distance

Study	Variable	20-29 years	30-39 years	40-49 years	50-59 years	60-69 years
EPAR2006	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	40	38	37	34	33
Present Study	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	45.2 ± 7.0	41.0 ± 5.7	34.9 ± 6.9	34.5 ± 4.4	30.3 ± 4.5
EPAG2006	3-minute walk distance (m)	375	360	360	345	345
Present Study	3-minute walk distance (m)	393 ± 61	377 ± 55	346 ± 45	364 ± 48	350 ± 45

EPAR2006, Exercise and Physical Activity Reference for Healthy Promotion 2006; EPAG2006, Exercise and Physical Activity Guide for Healthy Promotion 2006.

Table 3. Correlations matrix of $\dot{V}O_{2max}$ and independent variables

	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	Age (yrs)	BMI (kg·m^{-2})	%Fat (%)	WC (cm)
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	-				
Age (yrs)	-0.66**	-			
BMI (kg·m^{-2})	-0.45**	0.22*	-		
%Fat (%)	-0.67**	0.35**	0.70**	-	
WC (cm)	-0.66**	0.47**	0.84**	0.78**	-
3-minute walk distance (m)	0.54**	-0.24*	-0.23*	-0.41**	-0.40**

N = 127; *$P<0.01$. **$P<0.001$. BMI, body mass index; WC, waist circumference; %Fat, body fat percentage.

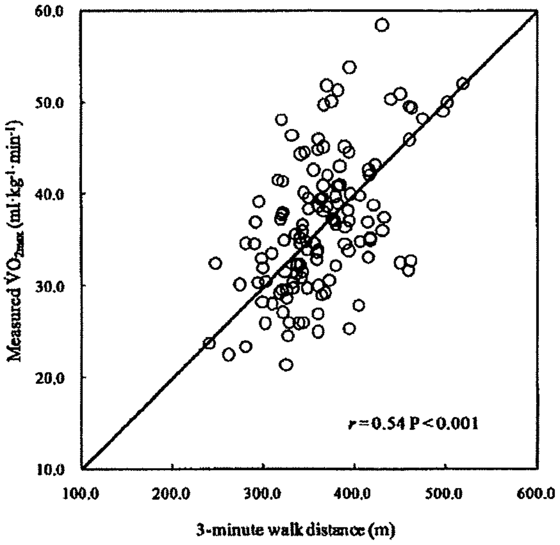


Figure 1. Relationships between the 3-minute walk distance and measured $\dot{V}O_{2max}$ values in the entire sample (n =127). The *solid line* is the line of equality (measured $\dot{V}O_{2max}$= 3-minute walk distance/10).

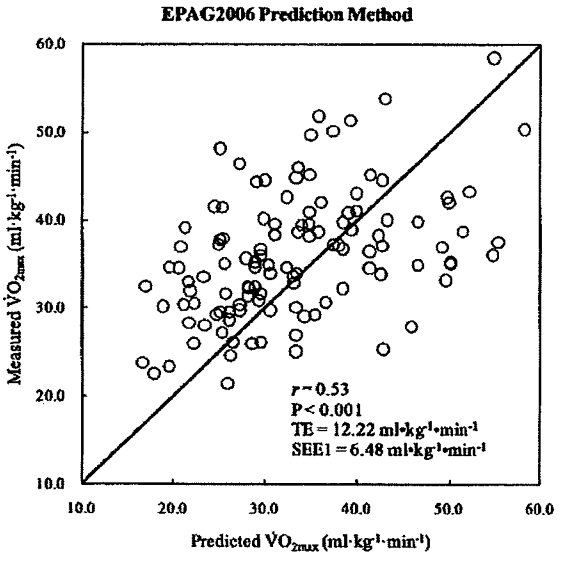


Figure 2. Relationships between the measured and predicted $\dot{V}O_{2max}$ values for the EPAG2006 prediction method in the entire sample (n =127). The *solid line* is the line of equality (measured $\dot{V}O_{2max}$=predicted $\dot{V}O_{2max}$).

C．3分間歩行テストを用いた$\dot{V}O_{2max}$の推定法（エクササイズガイド2006）の交差妥当性分析

エクササイズガイド2006で提案された3分間歩行テストを用いた$\dot{V}O_{2max}$推定法を本研究の対象者に適用したところ，$\dot{V}O_{2max}$の実測値と推定値との間には，中程度の正の相関関係（$r=0.53$, $P<0.001$）が認められ，合計誤差TEは12.2ml·kg^{-1}·min^{-1}，推定標準誤差SEE1は6.48ml·kg^{-1}·min^{-1}であった（Figure 2）．$\dot{V}O_{2max}$の実測値（36.7±7.6ml·kg^{-1}·min^{-1}）と推定値（36.6±14.4ml·kg^{-1}·min^{-1}）との間に有意差（P＝0.95）は認められなかった．

D．重回帰分析の結果

$\dot{V}O_{2max}$を従属変数とし，3分間歩行距離，年齢，BMI（BMI Model），腹囲（WC Model）および体脂肪率（%Fat Model）を独立変数に用いた重回帰分

析の結果をTable 4に示した．BMI Model，WC Modelおよび%Fat Modelの予測精度は，いずれもmodel 1よりmodel 2のほうが高かった．3分間歩行距離を独立変数として重回帰分析に加えると，推定式の寄与率はそれぞれBMI modelで11.7%，WC modelで7.7%，%Fat modelで6.0%増加した．%Fat model 2の予測精度が最も高かった（R＝0.85，SEE＝$4.1\,\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$，$P<0.001$）．PRESSの交差妥当性の結果もTable 4に示した．R^2pはわずかに減少し（0.019〜0.021），SEEpはわずかに増加

Table 4. Multiple regression nonexercise models estimation $\dot{V}O_{2max}$ $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$

		BMI Model $(\mathrm{kg \cdot m^{-2}})$		WC Model (cm)		%Fat Model (%)	
$\dot{V}O_{2max}$ $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$		Coefficients	β	Coefficients	β	Coefficients	β
Model1							
	Constant	71.829*		83.2081*		63.908*	
	Age (yr)	-0.324*	-0.592	-0.248*	-0.452	-0.266*	-0.486
	Body composition	-0.875*	-0.318	-0.428*	-0.452	-0.757*	-0.501
	R^2	0.54*		0.59*		0.65*	
	SEE $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$	5.243		4.871		4.494	
	SEE%	14.295		13.280		12.253	
	R^2p	0.51*		0.58*		0.64*	
	SEEp $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$	5.305		4.925		4.547	
Model2							
	Constant	46.749*		57.970*		45.939*	
	Age (yr)	-0.285*	-0.521	-0.236*	-0.432	-0.250*	-0.457
	Body composition	-0.691*	-0.251	-0.322*	-0.340	-0.606*	-0.401
	3-minute walk distance (m)	0.052*	0.360	0.044*	0.303	0.039*	0.270
	R^2	0.65*		0.67*		0.71*	
	SEE $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$	4.547		4.397		4.099	
	SEE%	12.397		11.988		11.176	
	R^2p	0.63*		0.65*		0.70*	
	SEEp $(\mathrm{ml \cdot kg^{-1} \cdot min^{-1}})$	4.610		4.463		4.163	

$^*P<0.0001$. BMI, body mass index; WC, waist circumference; %Fat, body fat percentage. β, standardized regression weights. SEE, standard error of estimate; SEEp, PRESS standard error of estimate; Rp, PRESS multiple correlation coefficients. SEE% calculated as (SEE/mean of measured $\dot{V}O_{2max} \times 100$).

した（0.063～0.066ml・kg^{-1}・min^{-1}）．

E．新しい推定式を用いて得られた$\dot{V}O_{2max}$の推定値と実測値との関係

本研究の推定式を用いて得られた$\dot{V}O_{2max}$の推定値は実測値と有意な差がみられなかった（Figure 3）．しかし，体力の高い被験者（$\dot{V}O_{2max}$＞40ml・kg^{-1}・min^{-1}）を対象に本研究で導出された$\dot{V}O_{2max}$の推定式を用いて$\dot{V}O_{2max}$を推定する場合，過小評価する傾向（7.7%）があることが示された．

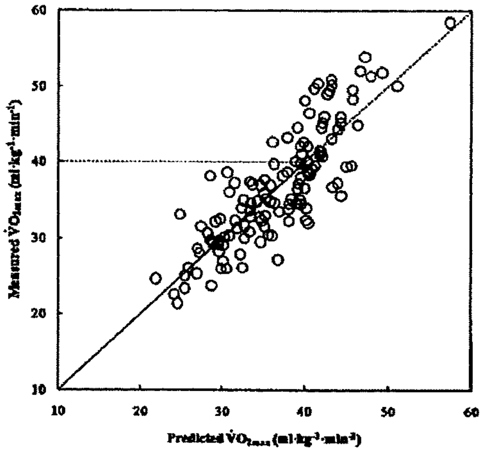
Ⅳ．考　　察

本研究では$\dot{V}O_{2max}$と年齢，身体組成及び3分間歩行距離との関係を検討するとともに，3分間歩行距離を用いた$\dot{V}O_{2max}$の推定式の開発と，その妥当性について検討した．その結果，$\dot{V}O_{2max}$と3分間歩行距離との間には，有意な正の相関関係（$r=0.54$，$P<0.001$）が認められ，$\dot{V}O_{2max}$と年齢及び身体組成との間にはそれぞれ有意な負の相関関係が認められた．

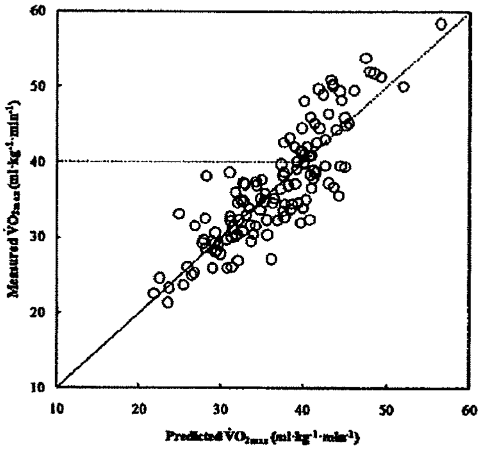
本研究の対象者は20～69歳の健康的な男性127名であった．$\dot{V}O_{2max}$の実測値と簡易な持久力の評価指標である3分間歩行テストの距離についてみると，年齢とともに低下している．年代別の3分間歩行テストの距離については，「エクササイズガイド2006」[7]に示された3分間歩行テストの距離の基準値に比べて，40代を除いて，各年代の平均値は高かった．年代別の$\dot{V}O_{2max}$については，40代と60代を除いて，各年代の平均値は「EPAR2006」[6]に示された$\dot{V}O_{2max}$の基準値より高い値を示した．また，すべての対象者は慢性疾病を有していないものであった．したがって，本研究の対象者は体力の面でも，病気の有無の面でも健康な集団であることがいえると考えられる．

今まで全身持久力測定ではフィールドテストを用いて$\dot{V}O_{2max}$を推定する研究が多くなされている[14]．テストの安全性や簡便性を考慮し，運動負荷に歩行を用いるテストが多く報告されている．その中でよく知られているのは6分間歩行（6MWD）と12分間歩行（12MWD）である．海外ではこのようなテストは$\dot{V}O_{2max}$との関係について，幾つかの研究により検証されたが，一致した結論は得られていない[13]．多くの研究では6MWD[15-17]及び12MWD[16,18]は

BMI Model



WC Model



%Fat Model

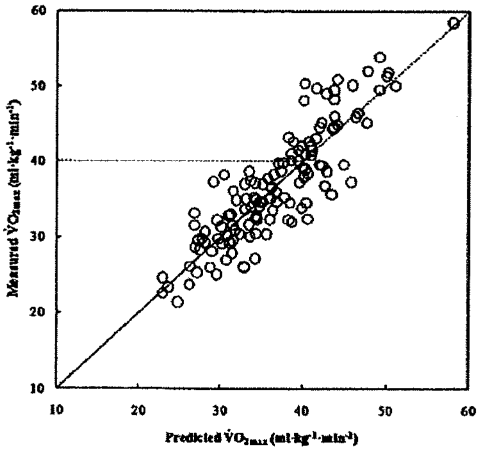


Figure 3. Relationships between the measured and predicted $\dot{V}O_{2max}$ values for the new multiple regression models in the entire sample (n =127). The *solid line* is the line of equality (measured $\dot{V}O_{2max}$ = predicted $\dot{V}O_{2max}$). The areas within the *dashed lines* show where the models tend to underestimate $\dot{V}O_{2max}$.

$\dot{V}O_{2max}$に有意な正の相関関係（r＝0.42～0.64，r＝0.49～0.52）があることを報告しているのに対し，Guyatt et al.[19]とEng et al.[20]は6MWDと$\dot{V}O_{2max}$との間に有意な相関関係が認められなかったと報告した．日本では，竹島ら[21]は，63～75歳の被験者18名対象とし，12MWDと$\dot{V}O_{2max}$との間に高い相関関係（r＝0.71）があることを報告している．また，Nakagaichi et al.[22]及び中垣内ら[23]は，成人男性を対象として，RPE13によって速度を調節する12分間歩行距離と$\dot{V}O_{2peak}$との間に高い相関関係（r＝0.73）があることを報告している．本研究では$\dot{V}O_{2max}$と3分間歩行距離との間の相関係数は0.54であり，先行研究で報告された6MWD[15～17]，12MWD[16,18,21]及びRPE13によって速度を調節する12分間歩行距離[22,23]と$\dot{V}O_{2max}$との相関係数の範囲（r＝0.42～0.73）に入っており，これらの先行研究に匹敵する相関関係が得られたことになる．これらの結果は，3分間歩行距離は$\dot{V}O_{2max}$を反映する重要な独立した予測因子であることが示唆され，3分間歩行テストが全身持久力の評価法として有用であることが示唆された．

「エクササイズガイド2006」[7]で提案された3分間歩行テストを用いた$\dot{V}O_{2max}$の推定法は，主観的運動強度が13（ややきつい）と感じる程度で3分間程度の歩行を実施し，その際の距離と時間から算出される速度（m／分）をもとに酸素摂取量を決定し，それを1.51倍することにより$\dot{V}O_{2max}$を推定する方法である[22,24]．しかし，このエクササイズガイド2006で提案された$\dot{V}O_{2max}$の推定法の交差妥当性を検討した研究はまだなされていない．したがって，本研究では健康な成人男性を対象として3分間歩行テストを用いた$\dot{V}O_{2max}$推定法（エクササイズガイド2006）の交差妥当性を検討した（Figure 2）．その結果，$\dot{V}O_{2max}$の実測値と推定値との間には，中程度の正の相関関係（r＝0.53，P＜0.001）が認められた．合計誤差率（TE%）は33.3%，推定標準誤差率（SEE1%）は17.7%であった．したがって，本研究結果からは健康な成人男性における$\dot{V}O_{2max}$の推定法（エクササイズガイド2006）の推定精度は低いと推察できる．

$\dot{V}O_{2max}$は性，年齢，身体組成などにより影響されることが明らかにされている．したがって，少数の関連性因子から$\dot{V}O_{2max}$を測定するよりは，$\dot{V}O_{2max}$に関連する多くの因子から$\dot{V}O_{2max}$を推定する方がより正確である．このような観点から，これまで多くの研究者によって重回帰法による$\dot{V}O_{2max}$の推定が試みられている[10,11,17,25～27]．Kline et al.[25]は年齢，性別，体重，1マイル歩行時間及び心拍数に基づいて$\dot{V}O_{2max}$の推定式を提示し，推定式のR＝0.93，SEE＝5.0ml･kg^{-1}･min^{-1}［実測値に対する比率(%SEE)＝13.5%］であることを報告している．また，Cahalin et al.[17]は年齢，体重，身長，心拍数及び6分間歩行距離に基づいて$\dot{V}O_{2max}$の推定式を提示し，推定式のR＝0.81，SEE＝2.7ml･kg^{-1}･min^{-1}（%SEE＝22.1%）であることを報告した．さらに，最大下運動負荷により推定される$\dot{V}O_{2max}$の%SEEは10～20%であることが報告されている[26]．本研究の%Fat modelのR＝0.85，SEE＝4.1ml･kg^{-1}･min^{-1}（%SEE＝11.2%）はこの範囲に入っており，これらの先行研究に匹敵する推定精度が得られたと言える．さらに，交差妥当性検定でも，R^2pはわずかに減少し，SEEpはわずかに増加したことから，本研究で導出された$\dot{V}O_{2max}$の推定式の精度は十分に保証されたと考えられる．以上のことから，本研究で導出された$\dot{V}O_{2max}$の推定式は妥当且つ有用な評価方法であることが示唆された．

本研究の推定式を用いて得られた$\dot{V}O_{2max}$の推定値は実測値と有意な差がみられなかった．しかし，体力の高い被験者（$\dot{V}O_{2max}$＞40ml･kg^{-1}･min^{-1}）を対象に本研究で導出された$\dot{V}O_{2max}$の推定式を用いて$\dot{V}O_{2max}$を推定する場合，過小評価する傾向（7.7%）があることが示された（Figure 3）．この結果は，3分間歩行テストによる$\dot{V}O_{2max}$の推定法の限界を示していると考えられる．Jackson et al.[27]やWier et al.[28]は，一般健常者を対象に質問紙を用いて$\dot{V}O_{2max}$を推定し，本研究と同様に$\dot{V}O_{2max}$の実測値が高い者ほど過小に推定したことを報告した．その解決方法として推定式の切片に定誤差（constant errors，＝体力の高い被験者の$\dot{V}O_{2max}$の実測値の平均値－体力の高い被験者の$\dot{V}O_{2max}$の推定値の平均値）を加えて使用することが提案された．本研究で導出された$\dot{V}O_{2max}$の推定式は主に市区町村自治体などの現場において対象者の全身持久性を評価し，低体力者をスクリーニングするために開発したものである．持久力の高い対象者（$\dot{V}O_{2max}$＞40 ml･kg^{-1}･min^{-1}）は「EPAR2006」で公表した生活習慣病発症