

Original Article

Attenuated Age-Related Carotid Arterial Remodeling in Adults with a High Level of Cardiorespiratory Fitness

Yuko Gando^{1,2}, Kenta Yamamoto², Hiroshi Kawano³, Haruka Murakami², Yumi Ohmori², Ryoko Kawakami², Kiyoshi Sanada⁴, Mitsuru Higuchi³, Izumi Tabata^{2,4}, and Motohiko Miyachi²

¹Sport Science Research Center, Waseda University, Saitama, Japan

²Health Promotion and Exercise Program, National Institute of Health and Nutrition, Tokyo, Japan

³Faculty of Sport Sciences, Waseda University, Saitama, Japan

⁴College of Sport and Health Science, Ritsumeikan University, Shiga, Japan

Aim: Cardiorespiratory fitness (CRF) is independently associated with a reduced risk of cardiovascular disease. Carotid arterial remodeling, which is derived from the interplay between carotid luminal dilation and wall thickening, is also an independent predictor of cardiovascular events. We hypothesized that high CRF may be associated with reduced age-related carotid arterial remodeling. This cross-sectional study was performed to determine the relationships between CRF and age-related luminal dilation and wall thickening.

Methods: A total of 771 adults (180 men and 591 women), under age 40 (young), 40-59 (middle-aged), and over age 60 (older) participated in this study. Subjects in each age category were divided into either high (fit) or low (unfit) CRF groups based on $\dot{V}O_{2\text{peak}}$. Carotid artery intima-media thickness (IMT) and lumen diameter were measured on ultrasound images. Carotid wall mass was calculated as $\rho L(\pi Re^2 - Ri^2)$.

Results: Two-way ANOVA indicated a significant interaction ($p < 0.01$) between age and CRF in determining IMT, lumen diameter, and wall mass. In older subjects, IMT, lumen diameter, and wall mass were significantly lower ($p < 0.05$) in the fit than in the unfit group (IMT, 0.69 ± 0.01 vs. 0.74 ± 0.01 mm; lumen diameter, 5.99 ± 0.06 vs. 6.28 ± 0.06 mm; wall mass, 7.41 ± 0.25 vs. 8.71 ± 0.25 mm³). Multiple regression analysis indicated that the value of $\dot{V}O_{2\text{peak}}$ was independently correlated with carotid IMT, lumen diameter and wall mass.

Conclusion: The present study indicated that a high level of CRF is associated with reduced age-related wall thickening and luminal dilation in the carotid artery.

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Key words; Aging, Fitness, Intima-media thickness, Lumen diameter, Remodeling

Introduction

Elastic arteries undergo remodeling with advancing age (intimal and medial thickening¹) and luminal dilation²). Arterial remodeling is usually an adaptive process that occurs in response to long-term changes in hemodynamic conditions, but may subsequently

contribute to the pathophysiology of vascular diseases and circulatory disorders.

Carotid artery intima-media thickness (IMT) is an independent risk factor for cardiovascular disease (CVD)^{3,4}. On the other hand, cardiorespiratory fitness (CRF) is independently associated with a reduced risk of CVD^{5,6}. Thus, many previous studies focused mainly on the relationships between the CRF level and the age-related increase in carotid IMT. In addition to carotid IMT, carotid arterial remodeling derived from the interplay between carotid luminal dilation and wall thickening⁷ is an independent predictor of cardiovascular events⁸. Previous studies sug-

Address for correspondence: Yuko Gando, Waseda University Sport Science Research Center, 2-579-15, Mikajima, Tokorozawa, Saitama, 359-1192, Japan

E-mail: gando-y@moegi.waseda.jp

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Table 1. Subject characteristics divided by age and fitness groups

	Young		Middle-aged		Older	
	Fit	Unfit	Fit	Unfit	Fit	Unfit
N	135	135	170	170	80	81
Men/Women, n	38/97	38/97	41/129	41/129	11/69	11/70
Age, years	28 ± 1	28 ± 1	50 ± 1*	51 ± 1*	63 ± 1*‡	64 ± 1*‡
Height, cm	164.2 ± 0.6	163.9 ± 0.7	160.0 ± 0.6*	160.1 ± 0.6*	156.9 ± 0.7*‡	156.9 ± 0.7*‡
Weight, kg	59.0 ± 0.9	59.3 ± 1.1	57.8 ± 0.8	61.7 ± 0.7†	54.2 ± 0.9*‡	55.9 ± 0.9‡
BMI, kg/m ²	21.6 ± 0.2	21.9 ± 0.3	22.4 ± 0.2*	24.1 ± 0.3*†	21.9 ± 0.3	22.6 ± 0.3‡
Body Fat, %	20.1 ± 0.4	24.8 ± 0.4†	23.9 ± 0.4*	30.4 ± 0.5*†	26.7 ± 0.6*	29.9 ± 0.5*†
SBP, mmHg	109 ± 1	109 ± 1	118 ± 1*	119 ± 1*	120 ± 2*	127 ± 2*‡†
DBP, mmHg	63 ± 1	64 ± 1	72 ± 1*	72 ± 1*	71 ± 1*	74 ± 1*
MAR, mmHg	81 ± 1	81 ± 1	91 ± 1*	91 ± 1*	92 ± 1*	97 ± 2*‡†
Carotid SBP, mmHg	102 ± 1	101 ± 1	117 ± 2*	118 ± 2*	121 ± 3*	131 ± 3*‡†
Plasma glucose, mmol/L	4.8 ± 0.1	4.8 ± 0.1	5.0 ± 0.1*	5.1 ± 0.1*†	5.2 ± 0.1*‡	5.3 ± 0.1*‡
Plasma insulin, μU/mL	5.1 ± 0.2	5.4 ± 0.2	4.1 ± 0.2*	5.0 ± 0.2†	4.3 ± 0.3	5.2 ± 0.5
Total cholesterol, mmol/L	4.55 ± 0.07	4.66 ± 0.06	5.39 ± 0.07*	5.39 ± 0.07*	5.78 ± 0.08*‡	5.80 ± 0.09*‡
HDL cholesterol, mmol/L	1.70 ± 0.03	1.58 ± 0.03†	1.76 ± 0.03	1.58 ± 0.03†	1.73 ± 0.04	1.64 ± 0.04
Triglycerides, mmol/L	0.72 ± 0.03	0.83 ± 0.04†	0.91 ± 0.04*	1.09 ± 0.05*†	0.95 ± 0.04*	1.04 ± 0.05*
LDL cholesterol, mmol/L	2.70 ± 0.06	2.91 ± 0.06†	3.44 ± 0.06*	3.59 ± 0.06*	3.86 ± 0.08*‡	3.95 ± 0.06*‡
$\dot{V}O_{2peak}$, mL/kg per min	41.1 ± 0.40	31.9 ± 0.3†	35.4 ± 0.4*	26.0 ± 0.3*†	32.2 ± 0.5*‡	23.7 ± 0.4*‡†

Data are the means ± SE. SBP, systolic blood pressure; DBP, diastolic blood pressure; MAR, mean arterial pressure; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; $\dot{V}O_{2peak}$, peak oxygen uptake.

* $p < 0.05$ vs. young subjects within the same fitness group; † $p < 0.05$ vs. middle-aged subjects within the same fitness group; ‡ $p < 0.05$ vs. fit subjects within the same age category.

gested that dilation of the lumen diameter is a typical vascular profile in patients with long-standing hypertension^{9, 10} and may reflect the fatiguing effects of repeated intense cyclic stress¹¹. Increased carotid wall mass according to luminal dilation and/or wall thickening is associated with an increased risk of cardiovascular events⁸. Thus, when considering the pathophysiological implications of vascular disease, it is also important not to overlook changes in both age-related carotid luminal dilation and wall thickening (arterial remodeling); however, the associations between the CRF level and age-related carotid arterial remodeling have attracted relatively little attention.

Accordingly, the primary aim of the present cross-sectional study was to determine the relationships between CRF and age-related carotid arterial remodeling. We hypothesized that higher CRF would be associated with reduced age-related carotid arterial remodeling.

Methods

Subjects

A total of 771 adults (180 men and 591 women), under the age of 40 (young), 40-59 years of age (mid-

dle-aged), and over the age of 60 (older) participated in this study (Table 1). None of the subjects smoked or were on medication for hypertension, hyperlipidemia, or diabetes. Subjects with a history of stroke, cardiac disease, chronic renal failure, or peripheral arterial disease, as well as those who regularly engaged in weight training, were excluded from the study¹². Subjects who demonstrated significant IMT (>1.5 mm), plaque formation¹³, ankle-brachial pressure index <0.90, and/or characteristics of atherosclerosis were excluded. Before testing, subjects abstained from caffeine and fasted for at least 4 hours (10-h overnight fast was used to determine metabolic risk factors and blood pressure (BP)). The purpose, procedures, and risks of the study were explained to each participant prior to inclusion, and all subjects gave their written informed consent before participating in the study, which was approved by the Human Research Committee of the National Institute of Health and Nutrition. The study was performed in accordance with the guidelines of the Declaration of Helsinki.

Carotid Artery IMT, Lumen Diameter, and Wall Mass

Carotid artery IMT and lumen diameter were

measured from ultrasound images (vivid i; GE Medical System) equipped with a high-resolution linear array transducer, as described previously^{14, 15}. Longitudinal two-dimensional ultrasound images were obtained at the proximal 1- to 2-cm straight portion of the common carotid artery. These images were first recorded on an ultrasound machine for later offline analysis, and then stored on hard disk. Carotid images were obtained by two trained investigators.

Ultrasound carotid images were analyzed using Image J image analysis software (National Institutes of Health, Bethesda, MD). Carotid IMT was defined as the distance from the leading edge of the lumen-intima interface to the leading edge of the media-adventitia interface¹⁴. Carotid lumen diameter was defined as the distance between the lumen and intima, and a near-wall boundary, corresponding to the interface of the adventitia and media. These measurements were made at end diastole, as described previously¹⁴. At least 10 measurements of IMT and lumen diameter were taken in each segment. The mean values of these 10 measurements were used for analysis. Carotid wall mass was calculated, as previously reported¹⁶, as $\rho L (\pi Re^2 - Ri^2)$, where ρ is the arterial wall density ($\rho = 1.06$)¹⁷, L is the length of the arterial segment ($L = 1$ cm), and Re and Ri are the mean external and internal radii, respectively. Image analyses were performed by two investigators blinded to the group assignment of the subjects. Intraobserver and interobserver variabilities of measurements were examined in 100 subjects. Intraobserver and interobserver variabilities of measurements were 3.7% and 4.2% for carotid IMT and 2.0% and 2.2% for the lumen diameter, respectively.

Carotid Arterial Blood Pressure

The pressure waveform and amplitude were obtained from the common carotid artery with a vascular testing device (PWV/ABI; Omron Colin, Kyoto, Japan). A multielement tonometry sensor, consisting of 15 pressure-sensitive small elements aligned side by side, was coupled to the device. The carotid tonometry sensor is compact and lightweight and can be easily attached around the neck. The sensor element, located manually at the center of the carotid artery, can be identified by screening the pulse pressure (PP) levels of the 15 elements provided that the sensor element is sufficiently small compared with the vessel diameter. The quality of the carotid pulse wave and the downward force were checked visually by carotid compression tonography, and pulse waves were recorded and stored over periods of 30 s. As baseline levels of BP are subjected to hold-down force, the pressure signal obtained by tonometry was calibrated

by equating the carotid mean arterial pressure (MAP) and diastolic blood pressure (DBP) to the brachial artery value¹⁸. Intraobserver variability of measurements was 4.0% for carotid systolic blood pressure (SBP).

Brachial Arterial Blood Pressure

Brachial BP was measured with an oscillometric device (PWV/ABI; Omron Colin) with subjects in the supine position. All measurements conformed to the American Heart Association Guidelines¹⁹.

Cardiorespiratory Fitness

CRF, assessed from peak oxygen uptake ($\dot{V}O_{2peak}$), was measured by an incremental cycle exercise test using a cycle ergometer (Ergonomic 828E Test Cycle; Monark, Varberg, Sweden) as described previously^{20, 21}. To assess the effects of CRF on carotid IMT, the subjects were categorized into high (fit) or low (unfit) CRF groups on the basis of the median value of $\dot{V}O_{2peak}$ in every decade of age in each sex.

Blood Samples

Blood samples were taken after an overnight fast of at least 10 h to determine fasting glucose and insulin levels. In the same session, serum samples were obtained to determine fasting total cholesterol, high-density lipoprotein cholesterol (HDL-cholesterol), low-density lipoprotein cholesterol (LDL-cholesterol) and triglyceride levels.

Statistical Analyses

The data were analyzed by two-way ANOVA (age \times fitness level) and ANCOVA, which included sex, brachial SBP and body fat as a covariate. In cases with a significant F value, a *post hoc* test with Scheffé's method was used to identify significant differences among mean values. Univariate regression and correlation analyses were used to analyze the relationships between variables of interest. Stepwise multiple regression analysis was used to determine the independent relations of several variables to arterial remodeling values. $P < 0.05$ was considered significant. Data are presented as the mean \pm SE.

Results

Table 1 shows the characteristics of the subjects. Age was associated with shorter stature, greater body fat, and higher blood pressure. The percent body fat value was lower in the fit group than in the unfit group at all ages.

Table 2 shows the effects of age and CRF on

Table 2. Arterial properties divided by age and fitness groups

	Young		Middle-aged		Older	
	Fit	Unfit	Fit	Unfit	Fit	Unfit
IMT, mm	0.56 ± 0.01	0.55 ± 0.01	0.66 ± 0.01 [*]	0.65 ± 0.01 [*]	0.69 ± 0.01 ^{*‡}	0.74 ± 0.01 ^{*‡†}
Lumen diameter, mm	5.88 ± 0.04	5.85 ± 0.04	5.85 ± 0.05	6.03 ± 0.05 ^{*†}	5.99 ± 0.06	6.28 ± 0.06 ^{*‡†}
Wall mass, mm ³	5.88 ± 0.12	5.73 ± 0.14	6.76 ± 0.16 [*]	7.06 ± 0.15 [*]	7.41 ± 0.25 ^{*‡}	8.71 ± 0.25 ^{*‡†}

Data are the means ± SE. IMT, intima-media thickness; ^{*} $p < 0.05$ vs. young subjects within the same fitness group; [‡] $p < 0.05$ vs. middle-aged subjects within the same fitness group; [†] $p < 0.05$ vs. fit subjects within the same age category.

carotid IMT, lumen diameter, and wall mass. Two-way ANOVA indicated a significant interaction ($p < 0.01$) between age and CRF in determining carotid IMT, lumen diameter, and wall mass. Carotid IMT and wall mass increased progressively with age in both fitness groups. Lumen diameter increased progressively with age in the unfit group but was not different at any age in the fit group. Carotid IMT and wall mass were lower ($p < 0.05$) in fit than in unfit older subjects and lumen diameter was lower ($p < 0.05$) in fit than in unfit middle-aged and older subjects. In the older group, these differences remained significant after normalizing for sex, brachial SBP and body fat as covariates; however, in the middle-aged group, the differences were abolished after normalizing for sex, brachial SBP and body fat. **Fig. 1** shows the relationships between $\dot{V}O_{2\text{peak}}$ and carotid IMT (A), lumen diameter (B), and wall mass (C) in each age category. Carotid IMT ($r = -0.24$, $p < 0.05$), luminal diameter ($r = -0.28$, $p < 0.01$), and wall mass ($r = -0.30$, $p < 0.01$) were correlated with $\dot{V}O_{2\text{peak}}$ in older subjects. There were no significant relationships in young or middle-aged subjects.

In older subjects, the analysis also indicated that carotid IMT was correlated with brachial SBP ($r = 0.29$), carotid SBP (0.28), weight (0.13), $\dot{V}O_{2\text{peak}}$ (-0.24), and HDL-cholesterol (-0.26). Stepwise multiple regression analysis revealed that brachial SBP ($\beta = 0.24$), HDL-cholesterol (-0.23), and $\dot{V}O_{2\text{peak}}$ (-0.16) were independently correlated with carotid IMT.

In older subjects, the analysis also indicated that lumen diameter was correlated with brachial SBP ($r = 0.43$), carotid SBP (0.39), weight (0.36), $\dot{V}O_{2\text{peak}}$ (-0.28), plasma glucose (0.24), plasma insulin (0.25), HDL-cholesterol (-0.16), and triglycerides (0.18). Stepwise multiple regression analysis revealed that brachial SBP ($\beta = 0.38$), weight (0.32), and $\dot{V}O_{2\text{peak}}$ (-0.16) were independently correlated with lumen diameter.

In older subjects, the analysis also indicated that

wall mass was correlated with brachial SBP ($r = 0.45$), carotid SBP (0.41), weight (0.33), $\dot{V}O_{2\text{peak}}$ (-0.30), HDL-cholesterol (-0.24), plasma insulin (0.23), plasma glucose (0.19), and triglycerides (0.16). Stepwise multiple regression analysis revealed that brachial SBP ($\beta = 0.42$), weight (0.28), and $\dot{V}O_{2\text{peak}}$ (-0.19) were independently correlated with wall mass.

Discussion

The key new findings of the present study were as follows. First, in the older group, carotid IMT, lumen diameter, and wall mass were significantly lower in the fit group than in the unfit group. Second, although carotid IMT and wall mass increased with age in both fitness groups, the magnitude of age-related increases was smaller in the fit group than in the unfit group. Third, carotid lumen diameter increased with advancing age in the unfit group but no differences were observed at any age in the fit group. Fourth, multiple regression analysis revealed that $\dot{V}O_{2\text{peak}}$ was independently correlated with carotid IMT, lumen diameter, or wall mass. These results suggested that higher CRF is associated with lower levels of age-related carotid arterial remodeling.

There have been many reports regarding the relationships between age-related increases in carotid IMT and CRF levels; however, these previous studies did not focus on the age-related dilation of the lumen diameter and increases in wall mass, and their findings were inconsistent. Specifically, the CRF level and habitual exercise have been reported to be associated with lower²²⁻²⁴, no difference²⁵⁻²⁷, or even greater²⁸ carotid IMT. Similar to previous findings by Galetta *et al.*²⁹, the present study also showed that a high level of CRF is related to an attenuation of age-related carotid arterial remodeling. An advantage of our study was the considerable number of subjects with a wide age range. Moreover, the strength of the present study was that CRF levels of all subjects were evaluated by maximal exercise testing. Considering the emphasis

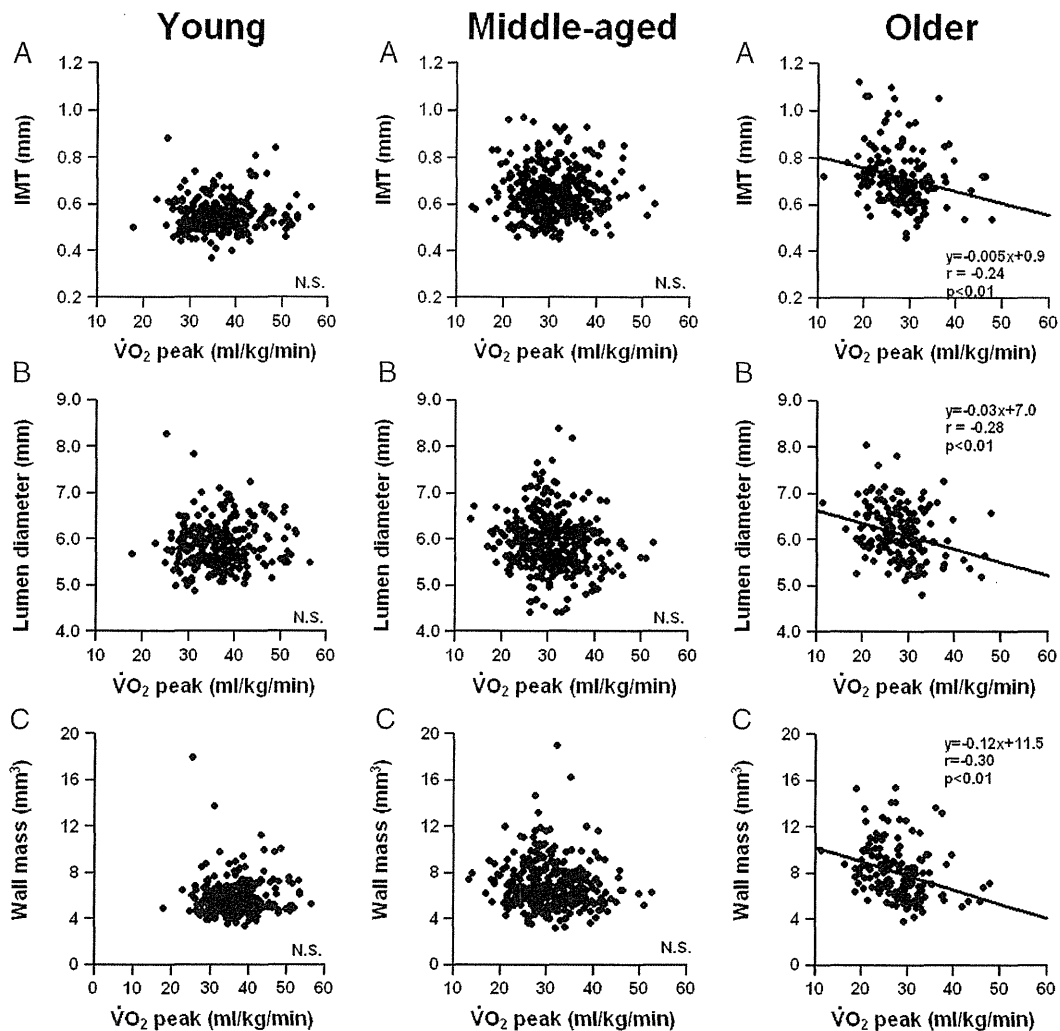


Fig. 1. Relationships between CRF and carotid IMT (A), lumen diameter (B), and wall mass (C) in each age category.

placed on dilation of the lumen diameter and increases in wall mass for prevention of CVD⁸⁾, we extended our research to age-related luminal dilation and wall thickening. Similar to some previous reports, the present study also showed that carotid IMT was lower in fit older subjects than in their unfit counterparts. More importantly, the present study demonstrated that lumen diameter and wall mass were lower in fit older subjects than in their unfit counterparts. The present findings suggested that higher CRF is associated with reduced age-related luminal dilation and wall thickening.

We can only speculate on the mechanisms responsible for the attenuation of age-related luminal dilation and wall thickening by higher CRF. Age-

related arterial remodeling is primarily an adaptive response of the arterial wall to progressive elevations in chronic arterial BP³⁰⁾. The results of animal and human studies indicated that an increase in distending pressure is a major stimulus for hypertrophy of smooth muscle cells and the synthesis of extracellular matrix in the arterial wall³¹⁻³⁴⁾. Repeated intense cyclic stress may cause fracture of the load-bearing elastin fibers and thus dilation of the lumen¹¹⁾. Therefore, we propose that the smaller degree of age-related luminal dilation and increase in wall mass in fit groups may be due to a smaller age-related increase in blood pressure. Indeed, in this study, brachial SBP and carotid SBP were positively associated with carotid IMT, lumen diameter or wall mass in older subjects. However, in a

stepwise multiple regression model that included these factors, $\dot{V}O_{2peak}$ was independently related to carotid IMT, lumen diameter, or wall mass. Park *et al.*³⁵ reported that wall internal area and wall thickness area of the aorta were increased by menopause and improved by regular exercise in an animal study. As noted by Park *et al.*, eNOS and endothelin-1 in the aorta tissue may participate in these mechanisms. Moreover, the mechanisms by which the maintenance of higher CRF may directly influence lumen diameter and wall mass are still speculative and include the effect of an endurance-trained state on the calcium content³⁶ and advanced glycation end products and collagen cross-linkage in the arterial wall³⁷. Exercise ameliorated the progression of endothelial dysfunction³⁸ and atherosclerotic lesion formation with a strong negative correlation between atherosclerotic areas and the mean running distance per day³⁹.

Our findings have a number of important implications. The present study showed that higher CRF was associated with smaller age-related increases in carotid IMT and wall mass and dilation of the lumen. As both luminal dilation and wall thickening are risk factors for CVD^{3, 4, 8}), the maintenance of higher CRF may have a protective effect against CVD in part by attenuating age-related carotid arterial remodeling; therefore, the improvement of CRF may be important for primary prevention of CVD.

A major limitation of the present study was its cross-sectional design. Due to the design of this study, we could not evaluate individual changes in age-related carotid arterial remodeling. A recent prospective study by Kozakova *et al.*²² reported that a period of vigorous activity influenced the 3-year IMT progression in a young to middle-aged population (30-60 yr). More research will be needed to determine cause-and-effect relationships in the older population (over 60 yr).

In conclusion, the present study indicated that a high level of CRF is associated with reduced age-related wall thickening and luminal dilation in the carotid artery.

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Disclosure

The authors declare no conflicts of interest.

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CALL FOR PAPERS *Functional Analysis of Sequence Variation*

PPAR γ 2 C1431T genotype increases metabolic syndrome risk in young men with low cardiorespiratory fitness

Kiyoshi Sanada,^{1,2} Motoyuki Iemitsu,¹ Haruka Murakami,³ Izumi Tabata,¹ Kenta Yamamoto,³ Yuko Gando,⁴ Katsuhiko Suzuki,⁴ Mitsuru Higuchi,⁴ and Motohiko Miyachi³

¹College of Sport and Health Science, Ritsumeikan University, Shiga; ²Consolidated Research Institute for Advanced Science and Medical Care, Waseda University; ³Health Promotion and Exercise, National Institute of Health and Nutrition, Tokyo; and ⁴Faculty of Sports Sciences, Waseda University, Tokorozawa, Japan

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Sanada K, Iemitsu M, Murakami H, Tabata I, Yamamoto K, Gando Y, Suzuki K, Higuchi M, Miyachi M. PPAR γ 2 C1431T genotype increases metabolic syndrome risk in young men with low cardiorespiratory fitness. *Physiol Genomics* 43: 103–109, 2011. First published December 14, 2010; doi:10.1152/physiolgenomics.00129.2010.—The peroxisome proliferator-activated receptor gamma 2 (PPAR γ 2) genotypes are related to obesity and the metabolic syndrome (MetS). A low level of cardiorespiratory fitness is also a strong determining factor in the development of MetS. This cross-sectional study was performed to investigate the influence of the interaction between the PPAR γ 2 genotype and cardiorespiratory fitness on the risk of MetS. Healthy Japanese men ($n = 211$) and women ($n = 505$) participated in this study. All subjects were divided into 8 groups according to sex, fitness level (high and low fitness groups), and age (younger, age < 40 yr; middle-aged/older, age \geq 40 yr). The PPAR γ 2 genotypes (Pro12Ala and C1431T) were analyzed by real-time PCR with Taq-Man probes. Two-way ANCOVA with adjustment for age as a covariate indicated that fitness and the CC genotype of C1431T in the PPAR γ 2 gene interacted to produce a significant effect on MetS risk in younger men and that the risk of MetS in the CC genotype group with low cardiorespiratory fitness was significantly higher than that in the corresponding CT+TT genotypes or in the high fitness groups. There was no significant interaction between fitness and genotype in determining MetS risk in middle-aged/older men or in women in any group. With regard to the Pro12Ala genotype of the PPAR γ 2 gene, there were no significant differences in fitness or genotype effects nor were there any interactions between measurement variables. We concluded that the CC genotype of C1431T in the PPAR γ 2 gene together with low cardiorespiratory fitness may increase the risk of MetS in younger men (age < 40 yr), even with adjustment for age.

physical fitness; peroxisome proliferator-activated receptor gamma 2; health care research; maximal oxygen uptake; obesity gene

THERE HAS BEEN A CONSIDERABLE increase in the number of studies reporting associations between DNA sequence variation in specific genes and obesity phenotypes (41). One such gene, that for peroxisome proliferator-activated receptor gamma 2 (PPAR γ 2), is reported to be associated with metabolic syndrome (MetS) or adipocytokine dysregulation (37, 52–53). Two common polymorphisms, a proline (Pro)-to-alanine (Ala) substitution located at codon 12 (Pro12Ala)(54) and a synonymous C-to-T substitution in exon 6 at nucleotide

1431 (C1431T)(30), have been associated with a reduced risk for the development of diabetes (33), a low adiponectin concentration (45), and an exercise-mediated change in insulin resistance (18) in Japanese people. The protective effect of the Ala allele of Pro12Ala against Type 2 diabetes has been replicated in Japanese, Caucasian-American, Finnish, and Danish populations; however, a deleterious effect of this allele on Type 2 diabetes has been demonstrated in Canadians, Germans, and obese Finns (28). Conversely, the CT+TT genotypes of C1431T in the PPAR γ 2 gene in Scotland (7) and in Greek children (22) are associated with increases in body mass index (BMI) and waist circumference compared with the CC genotype and are associated with a reduced risk for MetS in 647 Caucasian-Australian patients (26). However, some investigators have shown that the C1431T variant by itself is not associated with BMI or risk factors for MetS (14, 35).

Previous studies regarding the relationship between cardiorespiratory fitness and MetS suggested that a low level of physical fitness is a strong determining factor in the prevalence of MetS (6, 11, 23–25, 38, 50), because cardiorespiratory fitness is strongly correlated with physical activity (39). Lakka et al. (23) suggested that a sedentary lifestyle and an especially low cardiorespiratory fitness measured by maximal oxygen uptake ($\dot{V}O_{2max}$) are not only associated with MetS but could also be considered features of MetS. In addition, Lee et al. (25) reported that high levels of cardiorespiratory fitness are associated with a substantial reduction in health risk for a given level of visceral and subcutaneous fat. Therefore, it is important to consider individual cardiorespiratory fitness to clarify the relationship between PPAR γ 2 genotypes and MetS. The present study was performed to investigate the influence of interaction between the PPAR γ 2 genotype and cardiorespiratory fitness on the risk of MetS.

METHODS

Subjects. The subjects included in this cross-sectional study were 716 Japanese adults between 18 and 84 yr of age, consisting of 211 men and 505 women, as described previously were the same subjects included in Ref. 32. All subjects were free of any overt signs or symptoms of chronic disease. They were sedentary or moderately active subjects who participated in a swimming, stretching, and “healthy gymnastics” program; however, they did not participate in other vigorous sports activities. All subjects were divided according to sex and age (young < 40 yr old and middle-aged/older \geq 40 yr old), because metabolic profiles differ according to both sex and age. The

Address for reprint requests and other correspondence: K. Sanada, College of Sport and Health Science, Ritsumeikan Univ., 1-1-1 Noji Higashi, Kusatsu, Shiga 525-8577, Japan (e-mail: ksanada@fc.ritsumei.ac.jp).

purpose, procedures, and risks of the study were explained to each participant prior to enrollment, and all subjects gave their written informed consent before participating in the study, which was approved by the Human Ethical Committee of Waseda University. The study was performed in accordance with the guidelines of the Declaration of Helsinki. Body weight and height were recorded, and BMI was calculated as weight in kilograms divided by the square of the height in meters. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean blood pressure (MBP) were measured at rest by using a vascular testing device (Colin Medical Technology, Tokyo, Japan).

Measurements of blood samples. All blood samples were drawn from the subjects in the seated position. Fasting (> 12 h) blood samples were collected by venipuncture in tubes with or without ethylenediamine tetraacetic acid (for plasma or serum). The blood samples were centrifuged at 1,500 rpm for 15 min and stored at -20°C . Serum concentrations of triglycerides were determined by using commercial kits (Mitsubishi Chemical Medience, Tokyo, Japan). Serum high-density lipoprotein (HDL) cholesterol was measured by an enzymatic method (Mitsubishi Chemical Medience). Fasting plasma glucose (FPG) was measured by the glucose dehydrogenase method (21). Whole blood glycohemoglobin A1c (HbA1c) was measured by an enzymatic method (Glycohemoglobin A1c kit; Mitsubishi Chemical Medience). As waist circumference data were not available, the following risk factors of MetS (highest value = 4) were used: 1) BMI $\geq 25 \text{ kg/m}^2$; 2) blood pressure $\geq 130 \text{ mmHg}$ in systolic and/or $\geq 85 \text{ mmHg}$ in diastolic; 3) triglycerides $\geq 150 \text{ mg/dl}$ and/or HDL cholesterol $\leq 40 \text{ mg/dl}$; and 4) FPG $\geq 110 \text{ mg/dl}$. Moreover, MetS risk (Z-score) was derived by standardizing and then summing the following continuously distributed variables: BMI, MBP, HbA1c, and serum triglyceride/HDL cholesterol, to obtain the Z-score. It is known that a high serum triglycerides/HDL cholesterol ratio is one of the markers of insulin resistance (27). The BMI values can predict the presence of multiple metabolic risk factors similar to waist circumference in middle-aged Japanese subjects (43).

Measurement of $\dot{V}O_{2\text{max}}$. The $\dot{V}O_{2\text{max}}$ was measured by an incremental cycle exercise test using a cycle ergometer (Monark, Varberg, Sweden) (31). The incremental cycle exercise began at a work rate of 90 W (60 rpm), and power output was increased by 30 W/min until the subjects could not maintain the fixed pedaling frequency. The subjects were encouraged during the ergometer test to exercise at the level of maximum intensity. $\dot{V}O_2$ was monitored during the last 30 s of each increase in work rate. 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; Arco System, Chiba, Japan), and gas volume was determined by using a dry gas meter (NDS-2A-T; Shinagawa Dev., Tokyo, Japan). The highest value of $\dot{V}O_2$ during the exercise test was designated as $\dot{V}O_{2\text{max}}$. Moreover, these values were consistent with the reference values for the maximal oxygen uptake for health promotion by sex and age, as described by the

Japanese Ministry of Health, Labor, and Welfare to prevent life-style-related diseases (12, 17).

Single nucleotide polymorphism genotyping. Genomic DNA was extracted from plasma buffy coats and buccal cells by using a QIAamp DNA Blood Maxi Kit (Qiagen, Tokyo, Japan). Single nucleotide polymorphism (SNP) genotypes were determined by real-time PCR with TaqMan probes using an ABI Prism 7700 Sequence Detector (Perkin-Elmer Applied Biosystems, Foster City, CA) as described previously with minor modifications (16). The gene-specific primers and TaqMan probes for each SNP were synthesized by using Primer Express v. 1.5 software (Perkin-Elmer Applied Biosystems) according to the published DNA sequences for each SNP as follows: Pro12Ala (C>G) in exon 1 of PPAR γ 2 (NCBI accession ID: rs1805192) and C1431T in exon 6 of PPAR γ 2 (NCBI accession ID: rs3856806). The sequences of the oligonucleotides used were as follows:

Pro12Ala forward: 5'-GTTATGGGTGAACTCTGGGAGATT-3', Pro12Ala reverse: 5'-GCAGACAGTGTATCAGTGAAGGAAT-3', Pro12Ala/C probe: 5'-CTCCTATTGACCCAGAAAAG-3', Pro12Ala/G probe: 5'-CTATTGACGCAGAAAAG-3', C1431T forward: 5'-CA-GAAAATGACAGACCTCAGACAGA-3', C1431T reverse: 5'-CGTCTTCTTGATCACCTGCAGTAG-3', C1431T /G probe: 5'-CTGCACGTGTCCG-3', C1431T /A probe: 5'-CTGCACATGT-TCCG-3'.

PCR 96-well plates were read on an ABI-7700 using the end-point analysis mode of the SDS v. 1.7a software package (Perkin-Elmer Applied Biosystems). Genotypes were determined automatically by the single processing algorithms in the software.

Statistical analysis. The PPAR γ 2 allelic frequencies were calculated by using a gene-counting method, and Hardy-Weinberg equilibrium was confirmed by performing the χ^2 test. The variables BMI, MBP, HbA1c, and serum triglyceride/HDL cholesterol were standardized to Z-score variables with mean = 0 and standard deviation (SD) = 1 [(individual value - sex and age-specific mean value)/SD]. We tested the influence of genotype and fitness on the risk of MetS by using two-way ANCOVA with adjustment for age as a covariate (genotype and fitness), and when a significant difference was observed in the interaction, comparisons between groups were tested by using the unpaired Student's *t*-test. Regression analyses were conducted to explore the relationship between $\dot{V}O_{2\text{max}}$ and MetS risk, excluding variance produced by age by use of partial correlations (partial correlation coefficient). Values were expressed as means \pm SE. In all analyses, $P < 0.05$ was taken to indicate statistical significance.

RESULTS

There were no significant differences in the frequencies of C1431T and Pro12Ala polymorphisms between age groups in either sex (Table 1). The genotype frequencies did not deviate from the expected Hardy-Weinberg equilibrium.

Table 1. Genotype and allele frequencies of the peroxisome proliferator-activated receptor γ 2 gene

			Pro12Ala			C1431T		
			ProPro	ProAla	AlaAla	CC	CT	TT
Women	Age, yr <40	<i>n</i> (%)	197 (93.8)	12 (5.7)	1 (0.5)	137 (65.2)	69 (32.9)	4 (1.9)
		MAF			0.033		0.183	
	Age, yr \geq 40	<i>n</i> (%)	274 (92.9)	20 (6.8)	1 (0.3)	201 (68.1)	84 (28.5)	10 (3.4)
Men	Age, yr <40	<i>n</i> (%)	86 (93.5)	6 (6.5)	0 (0.0)	73 (79.3)	15 (16.3)	4 (4.3)
		MAF			0.033		0.125	
	Age, yr \geq 40	<i>n</i> (%)	113 (95.0)	6 (5.0)	0 (0.0)	85 (71.4)	28 (23.5)	6 (5.0)
		MAF			0.025		0.168	

MAF; minor allele frequency. There were no significant differences in the frequencies of C1431T and Pro12Ala polymorphisms between age in both sexes. The allele frequencies did not deviate from the expected Hardy-Weinberg equilibrium.

Significant simple and partial correlations (age-adjusted) were observed between $\dot{V}O_{2\max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and MetS risk (Z-score) in both men (simple correlation $r = -0.410$, $P < 0.001$, partial correlation $r = -0.371$, $P < 0.001$) and women (simple correlation $r = -0.309$, $P < 0.001$, partial correlation $r = -0.253$, $P < 0.001$); therefore, these findings were independently associated with age.

Neither C1431T nor Pro12Ala was associated with lower BMI regardless of age or sex in healthy Japanese adults. Women with low cardiorespiratory fitness in both age groups and in C1431T genotype groups had a higher BMI than those with high cardiorespiratory fitness ($P < 0.05$), but these associations did not hold for men (Tables 2 and 3). Low cardiorespiratory fitness in younger women of both C1431T genotypes was associated with higher SBP, DBP, and MBP than high cardiorespiratory fitness ($P < 0.05$), but this association was not observed in younger men or in middle-aged/older men and women. The risk of MetS in both C1431T genotypes of younger women with a low level of fitness was significantly higher than that in those with a high level of fitness ($P < 0.01$), but this association was absent in younger men and middle-aged/older people of either sex (Tables 2 and 3, respectively).

The interaction between fitness and genotype significantly affected the risk of MetS in younger men ($P < 0.05$, Fig. 1). Moreover, the MetS risk in low-fitness younger men with the

CC genotype in the C1431T polymorphism of the PPAR- γ 2 gene was significantly higher than that in the other groups ($P < 0.05$, Table 2). There was no significant interaction between fitness and genotype in determining MetS risk in middle-aged/older men and younger and middle-aged/older women.

On the other hand, with regard to the Pro12Ala genotype of the PPAR- γ 2 gene, there were no significant differences in fitness or genotype effects nor were there any interactions between measurement variables.

DISCUSSION

A previous study reporting associations between DNA sequence variation in specific genes and obesity phenotypes has increased considerably, with 426 findings of positive associations with 127 candidate genes (41). One of these genes, PPAR- γ 2, which encodes a transcription factor belonging to the nuclear receptor family, is related to lipid metabolism, carbohydrate metabolism, and fatty acid transport (51) and is a candidate gene for susceptibility to obesity and Type 2 diabetes (2, 8, 19, 34). It is directly involved in adipogenesis (46) and muscle responses to glucose (15). A common structural defect has been detected in the PPAR- γ 2 gene, resulting in a Pro-to-Ala substitution (54), located at codon 12 (Pro12Ala); and a

Table 2. Relationships among cardiorespiratory fitness, C1431T genotype of the peroxisome proliferator-activated receptor γ 2 gene, and metabolic syndrome risk in younger subjects (age <40 yr)

	CC Individuals With Low Fitness	CC Individuals With High Fitness	CT+TT Individuals With Low Fitness	CT+TT Individuals With High Fitness	P Genotype	P Fitness	P Interaction
<i>Women</i>							
<i>n</i>	46	91	23	50			
Age, yr	26.5 \pm 1.0	26.6 \pm 0.7	25.0 \pm 1.1	24.1 \pm 0.8			
Body mass index, kg/m^2	21.6 \pm 0.4	20.9 \pm 0.2	21.1 \pm 0.5	20.7 \pm 0.3	0.126	0.031	0.968
Systolic blood pressure, mmHg	105.3 \pm 1.5	107.4 \pm 0.9	103.5 \pm 1.7	105.5 \pm 0.9	0.353	0.001	0.718
Diastolic blood pressure, mmHg	62.1 \pm 1.3	61.7 \pm 0.7	59.9 \pm 1.3	59.5 \pm 0.7	0.561	0.001	0.847
Mean blood pressure, mmHg	79.1 \pm 1.4	79.3 \pm 0.8	76.0 \pm 1.3	77.0 \pm 0.8	0.286	0.000	0.965
Serum triglyceride, g/dl	68.7 \pm 4.6	57.2 \pm 2.4	61.9 \pm 4.3	60.3 \pm 3.0	0.521	0.683	0.199
HDL cholesterol, mg/dl	66.5 \pm 1.9	71.0 \pm 1.4	64.7 \pm 2.0	69.3 \pm 2.0	0.272	0.444	0.976
Serum triglyceride/ HDL cholesterol	1.09 \pm 0.09	0.83 \pm 0.04	0.99 \pm 0.08	0.90 \pm 0.05	0.299	0.987	0.185
Fasting plasma glucose, mg/dl	86.9 \pm 1.0	86.4 \pm 0.6	86.7 \pm 1.1	87.0 \pm 0.8	0.301	0.459	0.843
HgA1c, %	4.87 \pm 0.04	4.80 \pm 0.03	4.81 \pm 0.06	4.82 \pm 0.04	0.030	0.749	0.497
Number of MetS risk factors	0.24 \pm 0.08	0.07 \pm 0.03	0.04 \pm 0.04	0.02 \pm 0.02	0.281	0.027	0.233
MetS risk, Z-score	0.79 \pm 0.40	-0.34 \pm 0.17	-0.21 \pm 0.41	-0.44 \pm 0.25	0.078	0.005	0.317
Maximal oxygen uptake, $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	29.1 \pm 0.4	39.2 \pm 0.6	29.9 \pm 0.4	40.3 \pm 0.7	0.276	0.000	0.986
<i>Men</i>							
<i>n</i>	31	42	5	14			
Age, yr	34.8 \pm 0.7	27.2 \pm 1.0	33.4 \pm 2.1	25.5 \pm 1.9			
Body mass index, kg/m^2	25.5 \pm 0.8	23.2 \pm 0.4	22.9 \pm 0.6	23.4 \pm 0.4	0.446	0.285	0.080
Systolic blood pressure, mmHg	120.7 \pm 2.9	116.0 \pm 1.6	117.2 \pm 1.9	118.4 \pm 2.2	0.592	0.890	0.665
Diastolic blood pressure, mmHg	72.9 \pm 1.9	64.2 \pm 1.3	71.1 \pm 2.6	62.3 \pm 2.0	0.740	0.649	0.931
Mean blood pressure, mmHg	90.0 \pm 2.0	83.5 \pm 1.3	86.0 \pm 1.8	84.8 \pm 1.9	0.940	0.864	0.385
Serum triglyceride, g/dl	111.2 \pm 13.4	62.8 \pm 3.9	80.0 \pm 12.1	80.2 \pm 12.6	0.804	0.354	0.138
HDL cholesterol, mg/dl	49.3 \pm 1.4	60.7 \pm 1.7	56.2 \pm 5.5	63.6 \pm 3.6	0.274	0.078	0.245
Serum triglyceride/ HDL cholesterol	2.29 \pm 0.27	1.09 \pm 0.08	1.54 \pm 0.33	1.41 \pm 0.33	0.565	0.668	0.082
Fasting plasma glucose, mg/dl	90.3 \pm 1.2	90.4 \pm 1.5	88.6 \pm 3.5	92.9 \pm 1.3	0.496	0.513	0.277
HgA1c, %	4.79 \pm 0.04	4.75 \pm 0.04	4.64 \pm 0.13	4.76 \pm 0.08	0.080	0.686	0.093
Number of MetS risk factors	0.94 \pm 0.15	0.33 \pm 0.09 ^a	0.20 \pm 0.20 ^a	0.43 \pm 0.14 ^a	0.421	0.123	0.023
MetS risk, Z-score	2.14 \pm 0.67	-0.53 \pm 0.26 ^a	-0.27 \pm 0.67 ^a	0.01 \pm 0.65 ^a	0.287	0.891	0.029
Maximal oxygen uptake, $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	33.6 \pm 0.6	49.2 \pm 1.3	36.5 \pm 0.4	52.5 \pm 2.8	0.171	0.000	0.398

Data are means \pm SE unless otherwise indicated. ^a $P < 0.05$ for a significant difference from CC individuals of the C1431T variant with the "low fitness" group using the unpaired Student's *t*-test. *P* values are for significant effects using 2-way ANCOVA with adjustment for the covariate of age (genotype \times fitness). Boldface indicates significance ($P < 0.05$).

Table 3. Relationships among cardiorespiratory fitness, C1431T genotype of the peroxisome proliferator-activated receptor γ 2 gene, and metabolic syndrome risk in middle/older subjects (age \geq 40 yr)

	CC Individuals With Low Fitness	CC Individuals With High Fitness	CT+TT Individuals With Low Fitness	CT+TT Individuals With High Fitness	<i>P</i> Genotype	<i>P</i> Fitness	<i>P</i> Interaction
<i>Women</i>							
<i>n</i>	114	87	56	38			
Age, yr	55.7 \pm 0.8	53.7 \pm 1.0	57.9 \pm 1.2	54.9 \pm 1.2			
Body mass index, kg/m ²	23.6 \pm 0.3	21.6 \pm 0.3	23.8 \pm 0.4	21.9 \pm 0.4	0.657	0.002	0.831
Systolic blood pressure, mmHg	121.8 \pm 1.7	117.5 \pm 1.6	124.4 \pm 2.5	114.7 \pm 2.3	0.121	0.133	0.454
Diastolic blood pressure, mmHg	72.6 \pm 1.0	70.9 \pm 1.1	72.3 \pm 1.5	69.3 \pm 1.6	0.334	0.061	0.951
Mean blood pressure, mmHg	93.3 \pm 1.3	90.2 \pm 1.4	94.9 \pm 2.0	87.7 \pm 1.8	0.454	0.131	0.429
Serum triglyceride, g/dl	96.9 \pm 5.1	77.2 \pm 3.6	84.0 \pm 5.4	78.0 \pm 7.3	0.480	0.084	0.345
HDL cholesterol, mg/dl	64.6 \pm 1.2	73.1 \pm 1.8	66.9 \pm 1.5	73.4 \pm 3.6	0.060	0.009	0.534
Serum triglyceride/ HDL cholesterol	1.62 \pm 0.11	1.15 \pm 0.08	1.31 \pm 0.10	1.23 \pm 0.18	0.699	0.077	0.162
Fasting plasma glucose, mg/dl	95.4 \pm 1.5	92.0 \pm 0.9	95.1 \pm 1.8	90.2 \pm 1.0	0.540	0.354	0.844
HgA1c, %	5.16 \pm 0.06	5.00 \pm 0.04	5.17 \pm 0.08	5.07 \pm 0.05	0.536	0.341	0.376
Number of MetS risk factors	0.82 \pm 0.09	0.33 \pm 0.07	0.77 \pm 0.09	0.40 \pm 0.12	0.859	0.211	0.595
MetS risk, Z-score	0.91 \pm 0.25	-0.54 \pm 0.18	0.89 \pm 0.25	-0.45 \pm 0.31	0.479	0.325	0.698
Maximal oxygen uptake, ml·kg ⁻¹ ·min ⁻¹	24.3 \pm 0.4	34.6 \pm 0.5	24.4 \pm 0.4	33.4 \pm 0.7	0.887	0.000	0.140
<i>Men</i>							
<i>n</i>	54	31	22	12			
Age, yr	54.2 \pm 1.3	52.9 \pm 1.9	54.2 \pm 2.2	56.1 \pm 2.9			
Body mass index, kg/m ²	25.0 \pm 0.3	23.2 \pm 0.5	24.7 \pm 0.6	24.1 \pm 0.7	0.283	0.148	0.163
Systolic blood pressure, mmHg	124.9 \pm 2.1	126.6 \pm 2.6	129.5 \pm 3.2	125.3 \pm 4.1	0.666	0.565	0.258
Diastolic blood pressure, mmHg	78.9 \pm 1.4	78.4 \pm 2.0	78.7 \pm 2.1	80.1 \pm 3.0	0.657	0.347	0.757
Mean blood pressure, mmHg	96.7 \pm 1.9	97.6 \pm 2.5	98.3 \pm 2.8	95.6 \pm 3.6	0.803	0.273	0.401
Serum triglyceride, g/dl	122.3 \pm 8.3	111.0 \pm 8.9	118.2 \pm 14.7	109.6 \pm 15.7	0.926	0.414	0.979
HDL cholesterol, mg/dl	55.2 \pm 1.7	62.3 \pm 1.9	57.3 \pm 3.5	59.8 \pm 2.5	0.275	0.103	0.260
Serum triglyceride/ HDL cholesterol	2.45 \pm 0.21	1.94 \pm 0.21	2.29 \pm 0.33	1.91 \pm 0.30	0.964	0.155	0.856
Fasting plasma glucose, mg/dl	98.4 \pm 1.7	93.5 \pm 1.4	95.5 \pm 3.1	98.7 \pm 4.5	0.391	0.482	0.167
HgA1c, %	5.16 \pm 0.11	4.87 \pm 0.04	5.10 \pm 0.13	5.02 \pm 0.10	0.522	0.330	0.499
Number of MetS risk factors	1.20 \pm 0.14	0.97 \pm 0.16	1.41 \pm 0.20	1.17 \pm 0.24	0.483	0.385	0.996
MetS risk, Z-score	1.21 \pm 0.33	-0.16 \pm 0.38	1.00 \pm 0.52	0.26 \pm 0.40	0.991	0.952	0.549
Maximal oxygen uptake, ml·kg ⁻¹ ·min ⁻¹	28.9 \pm 0.6	39.7 \pm 0.7	29.0 \pm 0.9	38.1 \pm 1.4	0.779	0.026	0.463

Data are means \pm SE unless otherwise indicated.

synonymous C-to-T substitution in exon 6 has been identified at nucleotide 1431 (C1431T)(30) of this gene. However, the reported associations between increased body mass and BMI with the Pro12Ala genotype are inconsistent, with some studies indicating that the Ala allele is associated with either a higher BMI (3, 19, 29, 47) or a lower one (8–10, 40, 48), while other studies have found no association (13, 34, 42, 44). Kao et al. (19) reported that among overweight individuals (BMI 25–29.9 kg/m²), the ProAla genotype of PPAR γ 2 is associated with a higher BMI ($P = 0.02$), waist-to-hip ratio ($P = 0.01$), and waist circumference ($P = 0.04$) in nonobese African-Americans. Our data indicated that neither C1431T nor Pro12Ala variants were associated with a lower BMI regardless of age or sex of the healthy Japanese adults in the study groups.

Moderate and high levels of cardiorespiratory fitness attenuate the risk of all causes of and cardiovascular disease mortality in men with MetS (20). To date, many reports on the relationship between cardiorespiratory fitness and MetS have suggested that low physical fitness is a strong predictor for the presence of MetS (6, 11, 23–25, 38, 50). As cardiorespiratory fitness is closely correlated with physical activity (39), there may be an expectation that physical activity, such as cardiorespiratory fitness, would be related to health risk independently of abdominal obesity (25). However, the value of cardiorespiratory fitness in prevention of MetS has not been confirmed. Lakka et al. (23) reported that men with a $\dot{V}O_{2\max} < 29.1$ ml·kg⁻¹·min⁻¹ were almost seven times more likely to

have MetS than those with a $\dot{V}O_{2\max} \geq 35.5$ ml·kg⁻¹·min⁻¹ even after adjusting for confounding variables. In this study, significant partial correlations were observed between $\dot{V}O_{2\max}$ (ml·kg⁻¹·min⁻¹) and MetS risk in both men and women, even after adjustment for age; and the $\dot{V}O_{2\max}$ that corresponded to a MetS risk factor of 1 was shown to be 31.9 ml·kg⁻¹·min⁻¹ for men and 21.0·kg⁻¹·min⁻¹ for women, as determined by linear regression. These results suggest that low cardiorespiratory fitness was associated with MetS risk independent of age and that cardiorespiratory fitness levels corresponding to this risk may be used as target fitness values for prevention of MetS in Japanese adults.

At present, it is unclear which of the two contributions to MetS is more important: the PPAR γ 2 genotype or cardiorespiratory fitness. In the present study, the subjects were classified into high- and low-fitness groups according to the criteria issued by the Ministry of Health, Labor, and Welfare of Japan (17). We examined the relationship between the fitness level and PPAR γ 2 genotype, when the subjects were divided based on their sex and age. The results of this study indicated that younger men with low levels of fitness and the CC genotype of C1431T possessed more risk factors for MetS than those subjects with high fitness levels and the CT+TT genotypes, even after adjustment for age (Table 2 and Fig. 1). These results, therefore, suggest that in younger men (age < 40 yr) with the CC genotype of C1431T and low cardiorespiratory fitness, these factors increase the risk of MetS.

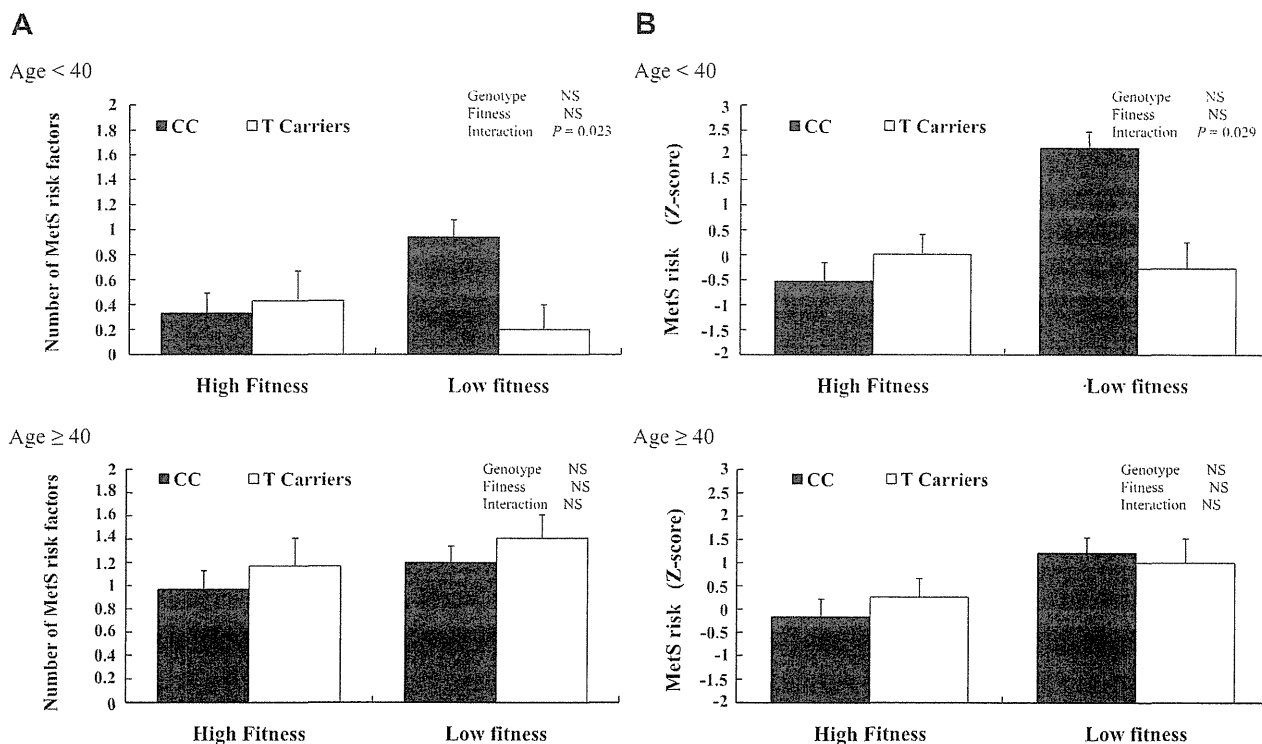


Fig. 1. Interaction between cardiorespiratory fitness and peroxisome proliferator-activated receptor γ 2 gene genotype (C1431T) with respect to the number of MetS risk factors (A) and MetS risk or Z-score (B) in men divided into 2 age groups (age < 40 yr and age \geq 40 yr). Genotype and fitness effects and interaction (genotype \times fitness) were assessed by 2-way ANCOVA with adjustment for age as a covariate. Data are expressed as means \pm SE. NS, not significant.

On the other hand, cardiorespiratory fitness itself is influenced not only by environmental factors such as daily physical activity but also by genetic factors. Bouchard et al. (4) reported a heritability estimate of \sim 50%, which was correlated with $\dot{V}O_{2max}$ in various parent-offspring and sibling relations, but not among the spouses. In the present study, there were no significant differences in $\dot{V}O_{2max}$ between the CC genotype and CT+TT genotypes of C1431T in the PPAR γ 2 gene in any of the groups (data not shown). Furthermore, in the human gene map for performance and health-related fitness phenotypes, the fitness and performance map now includes 214 autosomal gene entries and quantitative trait loci plus seven others on the X chromosome (5), but the PPAR γ 2 genotype is not included in these association studies with candidate genes. Therefore, the CC genotype of C1431T in PPAR γ 2 affects the relationship between cardiorespiratory fitness and MetS risk but does not separately affect each phenotype. One of the most interesting findings of the present study is that the CC genotype of C1431T in PPAR γ 2 in younger men, present in 79.3% of the subjects, was associated with MetS risk. These findings indicate that to prevent MetS, it is important to maintain high cardiorespiratory fitness in young male subjects with this genotype.

Some case-control studies have reported evidence of associations between the Pro12Ala genotype in PPAR γ 2 and responses of glucose and insulin metabolism phenotypes to habitual physical activity or regular exercise (1, 18, 36, 49). However, in the Pro12Ala variant of the PPAR γ 2 gene, there were no significant differences in fitness or genotype effects nor were there any interactions between measured variables as

determined by two-way ANCOVA in this study. Thus, the lower allele frequency for the Ala12 variant in Japanese (2–4%)(33, 45) compared with Europeans and North Americans (14–16%)(2, 10) may have affected these results.

In the present study, the interaction between fitness and genotype significantly affected the MetS risk in younger men, but not in younger women. Younger women in this study had fewer MetS risk factors than younger men, and therefore this effect of PPAR γ 2 polymorphism may be attenuated in women. However, in middle-aged/older subjects, no interaction between fitness and genotype was observed for either sex. An environmental factor with long-term exposure may participate in attenuation of the genetic factors. Additionally, the interpretation of the observations made in this cross-sectional study must be partly tempered due to the small sample size obtained when the subjects were divided based on their sex, age, fitness, and genotypes. Further study will be necessary using larger numbers of samples, and an intervention study should also be performed.

In conclusion, we found that low cardiorespiratory fitness was associated with MetS risk independent of age and that the CC genotype of C1431T in the PPAR γ 2 gene associated with low cardiorespiratory fitness increased the risk of MetS in younger men (age < 40 yr), even if these factors were adjusted for age.

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特定健診・保健指導の標準的な質問票を用いた身体活動評価の妥当性

川上 諒子* 宮地 元彦*

目的 本研究は、「標準的な健診・保健指導プログラム（確定版）」の標準的な質問票を用いた身体活動調査と3次元加速度計を用いて測定した歩数や身体活動量との比較を行うとともに、全身持久力との関係についても比較検討することを目的とした。

方法 被験者は、20から69歳までの成人男女483人であった。「標準的な健診・保健指導プログラム（確定版）」の標準的な質問票より、運動習慣、身体活動、歩行速度に関する3つの質問を用いた。質問は「はい」または「いいえ」で回答する形式であった。3つの質問に「はい」と回答した個数をもとに4つの活動レベルに分類した。歩数および身体活動量の測定には、3次元加速度計が用いられ、1日あたりの平均歩数、3メッツ未満、3メッツ以上、4メッツ以上の活動強度の身体活動量（メッツ・時）が測定された。さらに、運動負荷試験により最高酸素摂取量が測定され、全身持久力の指標とした。

結果 運動習慣、身体活動、歩行速度のいずれの質問においても、「はい」と答えた者は「いいえ」と答えた者より1日あたりの歩数、3メッツ以上および4メッツ以上の身体活動量ならびに全身持久力が有意に高いことが示された。「健康づくりのための運動基準2006」で示された身体活動量の基準において各質問による感度は62～73%、特異度は45～71%であった。また、活動レベル2をカットオフ値とした際に感度と特異度の和が最高となり、感度73%、特異度68%であった。全身持久力の基準における感度や特異度は、身体活動量の基準によるものよりもやや低かった。

結論 特定健診・保健指導の標準的な質問票を用いた身体活動調査によって、精度としてはそれほど高くないものの、簡易的な質問に回答するだけで日常の身体活動状況のある程度推定することが可能であることが示唆された。

Key words : 質問紙, 運動, 身体活動, 全身持久力, 特定健診・保健指導, 健康づくりのための運動基準2006

I 緒 言

身体活動量や全身持久力が高い者は生活習慣病の発症リスクが低いことが報告されている^{1~4)}。わが国では、平成18年に健康づくりのための身体活動量や全身持久力の基準値を定めた「健康づくりのための運動基準2006」および「健康づくりのための運動指針2006」が策定された^{5,6)}。また、平成20年4月からは、生活習慣病予防のために医療保険者に対して特定健康診査・特定保健指導の実施が定められた。そのため、近年では保健指導をはじめとする様々な場において対象者の身体活動量や全身持久力を

より簡便に評価できる方法が必要とされている。

身体活動量の評価法には、二重標識水法、心拍数法、加速度計法、歩数計法、生活活動記録法、質問紙法など様々な方法がある⁷⁾。中でも、質問紙法は他の評価法と比較して短時間で安価に行うことができ、誰もが容易に調査を行うことができるという利点を持つ。さらに、一度に多くの人を対象とした調査も可能であることから、疫学調査や保健指導の現場などでの活用が可能である。しかしながら、質問紙法には回答者の主観やあいまいな記憶などによるバイアスが入りやすく、客観性や正確性に乏しいという欠点もみられる。

平成19年に厚生労働省より「標準的な健診・保健指導プログラム（確定版）」が発表され⁸⁾、平成20年からは特定健診・保健指導で活用されている。このプログラムには、対象者のリスクや生活習慣状況を把握するための「標準的な質問票」が示されてお

* 独立行政法人国立健康・栄養研究所健康増進プログラム
連絡先：〒162-8636 東京都新宿区戸山1-23-1
独立行政法人国立健康・栄養研究所健康増進プログラム 宮地元彦

り、身体活動に関する質問も3問含まれている。質問内容は、「健康づくりのための運動基準2006」で定められた、週4メッツ・時の余暇時間における運動量、週23メッツ・時の身体活動量の基準が達成されているか否かを意図したものに加え、欧米の疫学研究で生活習慣病発症リスクとの関連が報告された日常の歩行速度に関する質問が活動強度や全身持久力の評価として含まれたものである⁹⁻¹¹⁾。しかしながら、この標準的な質問票を用いた身体活動の調査と実際の身体活動量や全身持久力とを比較した、日本人を対象とした報告はない。

そこで本研究では、標準的な質問票を用いた身体活動調査と3次元加速度計を用いて測定した歩数や身体活動量との比較を行うとともに、全身持久力との関係について比較検討を行うことを目的とした。

II 研究方法

1. 被験者

被験者は、20から69歳までの成人男女483名（男性178名、女性305名）であった。本研究を始めるにあたり、独立行政法人国立健康・栄養研究所における研究倫理審査委員会の承認を受けた。また、研究参加者には、本研究の目的や意義、危険性について事前に詳細な説明を行い、研究内容を十分に理解した上で研究参加への同意を得た。被験者の特性を表1に示す。

2. 測定項目および方法

1) 質問票による身体活動調査およびその分類

平成19年に厚生労働省より発表された「標準的な健診・保健指導プログラム（確定版）」の標準的な質問票より、身体活動に関する質問を用いた。回答

形式は「はい」または「いいえ」で回答する2件法であり、日記式法とした。質問内容は、「1回30分以上の軽く汗をかく運動を週2日以上、1年以上実施」（以下 運動習慣に関する質問）、「日常生活において歩行又は同等の身体活動を1日1時間以上実施」（以下 身体活動に関する質問）、「ほぼ同じ年齢の同性と比較して歩く速度が速い」（以下 歩行速度に関する質問）の3つとした。

また、運動習慣、身体活動、歩行速度の3つの質問の回答を組み合わせるにより、4つの活動レベルに分類した。3つの質問において「はい」と答えた個数が3つであった者を「活動レベル3」、2つであった者を「活動レベル2」、1つであった者を「活動レベル1」、そしてすべての質問に対して「いいえ」と答えた者を「活動レベル0」とした。

2) 歩数・身体活動量の測定

歩数および身体活動量の測定には、3次元加速度計（Actimarker EW4800：パナソニック電工社製）が用いられ、日常の身体活動が客観的に評価された。被験者は、加速度計を起床時から就寝時までの間、休日を含めて毎日20日間、腰部前方に装着した。1日あたりの平均歩数、および3メッツ未満、3メッツ以上、4メッツ以上の活動強度の身体活動量（メッツ・時）が測定された。

加速度計の大きさは60×35×13 mm、重さは24 g（電池込み）であった。加速度計には3軸方向（ x ：上下、 y ：左右、 z ：前後）の加速度センサーが内蔵されていた。1分毎の加速度値（Km）は、3軸の合成加速度の標準偏差として以下の式で算出された。

$$K_m = \sqrt{\frac{1}{n-1} \left[\left(\sum_{k=1}^n x_k^2 + \sum_{k=1}^n y_k^2 + \sum_{k=1}^n z_k^2 \right) - \frac{1}{n} \left\{ \left(\sum_{k=1}^n x_k \right)^2 + \left(\sum_{k=1}^n y_k \right)^2 + \left(\sum_{k=1}^n z_k \right)^2 \right\} \right]}$$

x_k, y_k, z_k は1分毎における各軸方向の加速度を示しており、 n は1分間にサンプリングされる個数である。加速度のサンプリング周波数は20 Hzであり、算出された加速度値は内蔵されたアルゴリズムによってメッツに変換され、1分毎に平均した値が時刻暦とともに内蔵メモリに蓄積された。この3次元加速度計の妥当性を検討した先行研究において、7種類の家事作業と7水準の歩行、走行速度における酸素摂取量との間に高い相関（ $r=0.93$ ）が認められている¹²⁾。また、二重標識水法によって測定された総消費エネルギー量との間にも高い相関（ $r=0.84$ ）が認められており、1次元の加速度計よりも精度が高いことが報告されている¹³⁾。

「健康づくりのための運動基準2006」で示された身体活動量の基準値「3メッツ以上の活動強度の身

表1 被験者特性

	男性	女性	全体
N	178	305	483
年齢（歳）	44±10	50±9	48±10
身長（cm）	170.3±5.5	157.0±5.5	161.9±8.5
体重（kg）	68.5±8.5	55.1±8.4	60.1±10.6
BMI（kg/m ² ）	23.6±2.6	22.4±3.3	22.8±3.1
歩数（歩/日）	1,0643±3,668	11,093±3,929	10,927±3,838
3メッツ未満の身体活動量（メッツ・時/日）	14.5±3.1	17.7±3.2	16.5±3.6
3メッツ以上の身体活動量（メッツ・時/日）	3.7±2.3	4.0±2.3	3.9±2.3
4メッツ以上の身体活動量（メッツ・時/日）	1.5±1.6	1.4±1.6	1.4±1.6
最高酸素摂取量（ml/kg/min）	35.6±7.8	29.4±6.2	31.7±7.5

平均値±標準偏差。

体活動を23メッツ・時/週」に相当する、1日あたり3.3メッツ・時を満した者を身体活動量の基準達成者とした。

3) 全身持久力の測定

全身持久力は、自転車エルゴメーター (Ergo-med 828E: Monark 社製) を用いた漸増負荷法により測定された。45~90 W で5分間のウォーミングアップを行かせた後、その強度から1分毎に15 W ずつ負荷を増加させ、疲労困憊まで至らした。なお、ペダルの回転数は毎分60回転とした。自覚的運動強度 (RPE) が17を越えた頃を目安とし、運動終了前の2~3分間程度、疲労困憊に至るまで30秒毎に運動中の呼気ガスを採取した。呼気ガスの分析には、自動質量分析機 (ARCO-1000: アルコシステム社製) が用いられ、酸素および二酸化炭素の濃度が測定された。さらに、乾式ガスメータ (DC-5: 品川社製) を用いて換気量が測定され、酸素摂取量が算出された。測定により得られた酸素摂取量の最高値を最高酸素摂取量とし、全身持久力の指標とした。運動中は、ハートモニター (Life Scope 6: 日本光電社製) により、心電図および心拍数が連続的にモニタリングされた。

「健康づくりのための運動基準2006」で示された性・年代別の全身持久力 (最大酸素摂取量) の基準値を表2に示した。この基準値を満した者を全身持久力の基準達成者とした。

3. 統計処理

測定値は、平均値±標準偏差、または95%信頼区間で示した。各質問の回答および3つの質問の組合せによる活動レベル間の連続変数 (歩数・身体活動量・全身持久力など) の平均値や分布の比較には一元配置分散分析を用いた。なお、各質問や活動レベルにおいて年齢や性別で有意差が認められた場合には、有意差が認められた因子をそれぞれ共変量とした共分散分析を用い解析をした。多重比較検定には Student Newman-Keuls 法を用いた。また、各質問の回答および3つの質問の組合せによる活動レベル間のカテゴリー変数 (「健康づくりのための運動基準2006」で示された身体活動量および全身持久力の基準達成者の割合など) の頻度の比較には χ^2 検定

を用いた。統計的有意水準はすべて5%未満とした。

各質問の回答および3つの質問を組合せた活動レベルによる身体活動量と全身持久力の評価の妥当性を検証するために、各質問と活動レベルごとに、感度、特異度、陽性反応適中度、陰性反応適中度を算出した。

III 研究結果

1. 各質問の回答による比較

各質問の回答結果における歩数、身体活動量を表3に示した。1日あたりの平均歩数、3メッツ以上および4メッツ以上の身体活動量に関して、運動習慣、身体活動、歩行速度のいずれの質問においても「はい」と答えた者は「いいえ」と答えた者よりそれぞれ統計上有意に高い値が認められた。3メッツ未満の身体活動量においては、3つのいずれの質問に対する回答結果においても有意な差が認められなかった。

全身持久力は、運動習慣、身体活動、歩行速度のいずれの質問においても「はい」と答えた者は「いいえ」と答えた者と比較してそれぞれ統計上有意に高い値が認められた (表3)。

2. 3つの質問の組み合わせによる比較

3つの質問を組み合わせることで得られた活動レベルと歩数、身体活動量の関連を表4に示した。歩数および4メッツ以上の身体活動量は、活動レベル0, 1の者と比較して、2および3の者で統計上有意に高い値が認められた。3メッツ以上の身体活動量は、すべての活動レベル間で有意な差が認められ、活動レベルが高い者ほど統計上有意に高い値となった。3メッツ未満の身体活動量においては、活動レベル間で有意な差がなかった。

3つの質問の活動レベルにおける全身持久力を表4に示した。活動レベル2および3の者は、活動レベル0, 1の者と比較して全身持久力が統計上有意に高かった。さらに、活動レベル3の者は、活動レベル2の者よりも有意に高い値が認められた。

3. 質問の回答と「健康づくりのための運動基準2006」

各質問の回答結果と「健康づくりのための運動基準2006」で示された身体活動量および全身持久力の基準達成状況を表5に示した。身体活動量の基準達成者のうち「はい」と答えた者は、いずれの質問においても「いいえ」と答えた者より統計上有意に多かった。全身持久力の基準では、運動習慣と身体活動の質問において基準達成者で「はい」と回答した者が「いいえ」と回答した者より有意に多かった。

3つの質問の活動レベルにおける基準達成状況を

表2 健康づくりのための全身持久力 (最大酸素摂取量) の基準値 (ml/kg/min)

	20歳代	30歳代	40歳代	50歳代	60歳代
男性	40	38	37	34	33
女性	33	32	31	29	28

「健康づくりのための運動基準2006」。

表3 各質問の回答による歩数・身体活動量および全身持久力

	運動習慣		身体活動		歩行速度		P値
	はい	いいえ	はい	いいえ	はい	いいえ	
N	231	252	256	227	317	166	
性別 (男性/女性)	79/152	99/153	75/181	103/124	115/202	63/103	0.717
年齢 (歳)	49±10	46±10	48±10	47±10	48±10	47±10	0.319
歩数 (歩/日)	12,105 (11,626-12,584)	9,847 (9,389-10,305)	12,018 (11,565-12,471)	9,697 (9,215-10,178)	11,246 (10,825-11,667)	10,319 (9,737-10,901)	0.012
3メッツ未満の身体活動量 (メッツ・時/日)	16.4 (15.9-16.8)	16.7 (16.3-17.1)	16.8 (16.4-17.2)	16.3 (15.8-16.7)	16.6 (16.2-17.0)	16.4 (15.9-17.0)	0.581
3メッツ以上の身体活動量 (メッツ・時/日)	4.7 (4.4-5.0)	3.2 (2.9-3.5)	4.5 (4.2-4.8)	3.3 (3.0-3.6)	4.2 (4.0-4.4)	3.4 (3.1-3.7)	<0.001
4メッツ以上の身体活動量 (メッツ・時/日)	2.0 (1.8-2.1)	1.0 (0.8-1.2)	1.8 (1.6-2.0)	1.1 (0.9-1.3)	1.6 (1.4-1.8)	1.1 (0.9-1.4)	0.003
最高酸素摂取量 (ml/kg/min)	34.5 (33.7-35.3)	29.2 (28.4-29.9)	32.7 (31.9-33.6)	30.6 (29.7-31.5)	32.2 (31.4-33.1)	30.7 (29.6-31.9)	0.033

平均値±標準偏差, または (95%信頼区間)。運動習慣の質問結果は年齢で調整。身体活動の質問結果は性別で調整。

図1, 2に示した。身体活動量の基準において, 活動レベル2および3であった者は活動レベル0, 1の者と比較して基準達成者が統計上有意に多かった。また, 全身持久力の基準達成者は, 活動レベル3の者が活動レベル0, 1の者より有意に多かった。

4. 各質問の回答による感度・特異度

各質問における感度, 特異度, 陽性反応適中度および陰性反応適中度の結果を表5に示した。身体活動量の基準において, 各質問の感度は62から73%, 特異度は45から71%であった。全身持久力の基準では, 各質問における感度が61から70%, 特異度が38から66%であった。どちらの基準においても, 歩行速度の質問における感度が最も高く, 特異度は運動習慣の質問が最も高かった。

5. 3つの質問の組み合わせによる感度・特異度

3つの質問を組み合わせた活動レベルによる感度・特異度等の結果および Receiver Operating Characteristic (ROC) 曲線を図1, 2に示した。身体活動量と全身持久力の基準どちらにおいても, 活動レベル2をカットオフ値とした際に感度と特異度の和が最高となることが示された。身体活動量の基準において, 活動レベル2をカットオフ値とした際の感度は73%, 特異度は68%であった。全身持久力の基準においては感度69%, 特異度54%であった。

IV 考 察

本研究では, 「標準的な健診・保健指導プログラム (確定版)」の標準的な質問票を用いた身体活動調査と3次元加速度計を用いて測定した歩数や身体活動量との比較を行うとともに, 全身持久力との関係についても比較検討した。

本研究における平均歩数は10927歩であり, 平成19年に発表された国民健康栄養調査の平均歩数 (男性7,321歩, 女性6,267歩) を大きく上回っていた¹⁴⁾。したがって, 本研究の被験者は身体活動量の高い集団であったと考えられる。

1. 標準的な質問票の回答と加速度計で測定した身体活動量

運動習慣, 身体活動, 歩行速度のいずれの質問においても, 「はい」と答えた者は「いいえ」と答えた者より1日あたりの歩数, 3メッツ以上および4メッツ以上の身体活動量が統計上有意に高いことが示された。また, 3つの質問を組み合わせることによって得られた活動レベルと加速度計で評価した歩数, 3メッツ以上ならびに4メッツ以上の強度の身体活動量との間には量反応関係がみられた。一方, 3メッツ未満の身体活動量は, いずれの質問においても回答結果で有意な差が認められなかった。歩行

表4 3つの質問の活動レベルによる歩数・身体活動量および全身持久力

	活 動 レ ベ ル				P 値	F 値
	0	1	2	3		
N	58	156	159	110		
性別 (男性/女性)	28/30	63/93	55/104	32/78	0.063	
年齢 (歳)	47±9	46±10	47±10	50±10*†	0.005	4.4
歩数 (歩/日)	8,925 (8,007-9,844)	9,440 (8,878-10,002)	11,879*† (11,325-12,433)	12,716*† (12,043-13,388)	<0.001	27.7
3 メッツ未満の身体活動量 (メッツ・時/日)	16.0 (15.1-16.9)	16.5 (15.9-17.0)	16.7 (16.2-17.3)	16.6 (16.0-17.3)	0.566	0.7
3 メッツ以上の身体活動量 (メッツ・時/日)	2.5 (2.0-3.0)	3.1* (2.8-3.4)	4.4*† (4.1-4.7)	5.1*†† (4.7-5.5)	<0.001	32.1
4 メッツ以上の身体活動量 (メッツ・時/日)	0.6 (0.3-1.0)	0.9 (0.7-1.2)	1.7*† (1.4-1.9)	2.2*†† (2.0-2.5)	<0.001	23.0
最高酸素摂取量 (ml/kg/min)	28.7 (27.1-30.2)	29.8 (28.8-30.7)	32.2*† (31.3-33.2)	35.4*†† (34.2-36.5)	<0.001	22.9

平均値±標準偏差, または (95%信頼区間)。活動レベルの結果は年齢で調整。

*: 活動レベル0の者との有意差。

†: 活動レベル1の者との有意差。

††: 活動レベル2の者との有意差。

表5 各質問の回答による感度・特異度

身体活動量の基準

		基準達成者 (N)	基準未達成者 (N)	感度 (%)	特異度 (%)	陽性反応適中度 (%)	陰性反応適中度 (%)	P 値
運動習慣	はい	171	60	61.7	70.9	74.0	58.0	<0.001
	いいえ	106	146					
身体活動	はい	177	79	63.9	61.7	69.1	56.0	<0.001
	いいえ	100	127					
歩行速度	はい	203	114	73.3	44.7	64.0	55.5	<0.001
	いいえ	74	92					

全身持久力の基準

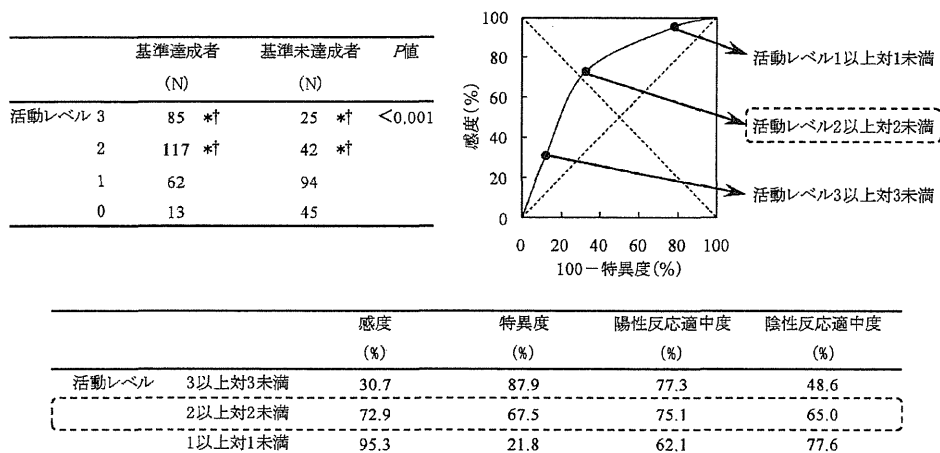
		基準達成者 (N)	基準未達成者 (N)	感度 (%)	特異度 (%)	陽性反応適中度 (%)	陰性反応適中度 (%)	P 値
運動習慣	はい	136	95	65.7	65.6	58.9	71.8	<0.001
	いいえ	71	181					
身体活動	はい	127	129	61.4	53.3	49.7	64.8	0.002
	いいえ	80	147					
歩行速度	はい	145	172	70.0	37.7	45.8	62.6	0.077
	いいえ	62	104					

P 値は χ^2 検定。

の活動強度は、普通歩行で3メッツ、速歩が4~5メッツである¹⁵⁾。したがって、歩行強度以下の家事やオフィスワークなどといった低強度の活動は標準的な質問票を用いた身体活動調査の結果に反映されにくいと推察される。

「健康づくりのための運動基準2006」で示された身体活動量の基準値に相当する3.3メッツ・時/日(23メッツ・時/週)の基準達成者のうち、各質問において「はい」と回答した者の割合(感度)は、62~73%であった。また、基準未達成者のうち「いい

図1 身体活動量の基準における活動レベルの感度・特異度



左上：各活動レベルにおける身体活動量の基準達成状況。P値は χ^2 検定。

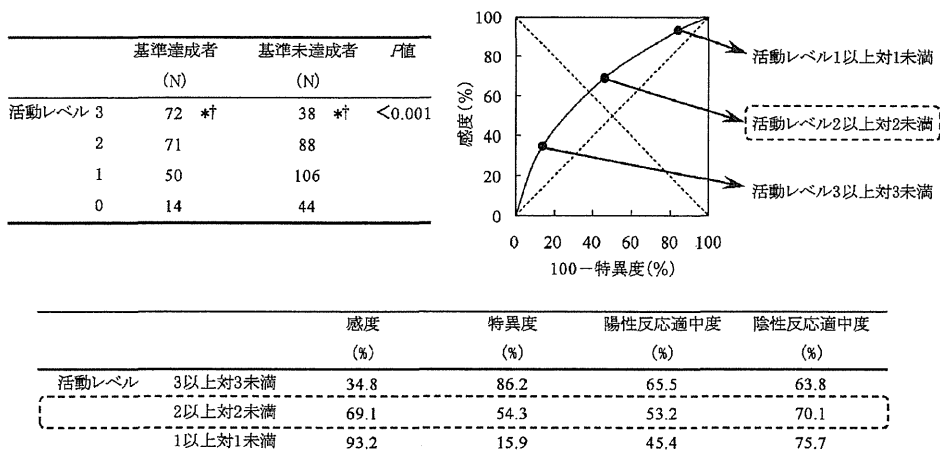
*：活動レベル0の者との有意差。

†：活動レベル1の者との有意差。

右上：ROC曲線。

下：活動レベルに基づいて分類した際の感度・特異度。

図2 全身持久力の基準における活動レベルの感度・特異度



左上：各活動レベルにおける全身持久力の基準達成状況。P値は χ^2 検定。

*：活動レベル0の者との有意差。

†：活動レベル1の者との有意差。

右上：ROC曲線。

下：活動レベルに基づいて分類した際の感度・特異度。

え」と答えた者の割合（特異度）は45～71%であった。とくに、運動習慣および身体活動の質問においては、感度と特異度がともに6割以上であった。また、活動レベル2をカットオフ値とした際に感度と特異度の和が最高となることが明らかとなり、感度は73%、特異度は68%であった。

以上の結果から、精度はそれほど高くないものの、簡易的な質問に回答するだけで身体活動状況をある程度推定することが可能であることが示唆された。

2. 標準的な質問票の回答と運動負荷試験で測定した全身持久力

運動習慣、身体活動、歩行速度のそれぞれの質問において、「はい」と答えた者の全身持久力は「いいえ」と答えた者よりも有意に高いことが示された。また、活動レベルと全身持久力の間には量反応関係がみられた。一般に、比較的高い強度で運動トレーニングを行うと全身持久力は向上する^{16,17)}。また、歩数・歩行速度や身体活動量が高い者は全身持久力が高いことが先行研究で報告されてい