[Environmental Health and Preventive Medicine 8, 173–177, November 2003]

Original Article

Factors Affecting the Estimated Maximal Oxygen Uptake: a Follow-Up Study of Participants in the Total Health Promotion Plan

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Abstract

Objectives: To elucidate the effects of risk factors for arteriosclerosis on estimated $\dot{V}O_2$max and obtain useful information to advise enterprise employees.

Subjects: One hundred and nineteen male and 87 female enterprise employees underwent exercise tests for health evaluation in the Total Health Promotion Plan at the Fukui Occupational Health Center between April 1990 and March 1993.

Methods: Multiple regression analysis was performed using estimated $\dot{V}O_2$max as the dependent variable, and percent body fat, blood pressure, blood tests, habitual physical activity, number of cigarettes smoked and alcohol consumption as independent variables in the first and second year, and for yearly changes in these variables.

Results: The significant variables selected were as follows: in the first year, systolic blood pressure and percent body fat in males, and age in females; in the second year, diastolic blood pressure and habitual physical activity in males and systolic blood pressure in females; for yearly changes in each variable, cigarettes in males and percent body fat in females were selected.

Conclusion: It was suggested that guidance to reduce cigarettes in males, and to keep a proper percent body fat in females would be effective in maintaining the estimated $\dot{V}O_2$max.

Key words: maximal oxygen uptake, $\dot{V}O_2$max, cigarette smoking, body fat, exercise habits

Introduction

The Japanese demographic distribution is progressing toward aging, and the ratio of advanced-aged workers in the work force is increasing. It is an important issue for enterprises to create a working environment that promotes workers' health and allows them to use their abilities to the fullest. The Total Health Promotion Plan (THP) is concerned with the health care of Japanese enterprise employees under the Industrial Safety and Health Law, revised in 1988, in response to the WHO Ottawa Charter issued in 1986. The THP includes inquiry into health conditions, investigation of life style, consultation for mental health, medical examination, motor function test, and preparation of exercise instruction cards. For the THP, employers have to take appropriate measures to counsel individual workers based on health condition data via the THP.

Maximal oxygen uptake ($\dot{V}O_2$max) has been reported to be a useful comprehensive index of health status and physical fitness (1). $\dot{V}O_2$max is also reported to be closely related to risk factors for arteriosclerosis (2, 3), which cause heart diseases and cerebro-vascular disorders, the second and third most frequent causes of death among Japanese (4), respectively. Our recent report from a cross-sectional study on workers under the THP also showed that estimated $\dot{V}O_2$max was related to body fat and blood pressure (5).

The THP includes measurement of $\dot{V}O_2$max as an index representing physical work capacity. The estimated $\dot{V}O_2$max in the THP is measured by a sub-maximal exercise test. Although estimated $\dot{V}O_2$max is considered to contain an error of 10–15% compared with the value actually measured by respiratory gas analysis, it can be relatively safe for individuals using a computer program incorporated in a bicycle ergometer. Therefore, the estimated $\dot{V}O_2$max is usually used in the health check-up for the THP.

The objective of this study was to analyze the two-year

Received Apr. 11 2003/Accepted Aug. 8 2003
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continuous data obtained by the THP and to clarify the factors related to estimated $\dot{V}O_2max$ in enterprise workers. In particular, we evaluated the effects of risk factors for arteriosclerosis and lifestyle factors on estimated $\dot{V}O_2max$.

Subjects and Methods

According to the Industrial Safety and Health Law, the Japan Assembly approved THP policy in association with the budget. In line with this, the Japan Industrial Safety and Health Association (JISHA) has a contract with the Ministry of Health, Labor and Welfare, to perform examinations. Fukui Occupational Health Center is one of the cooperating institutions entrusted by JISHA.

The ethics committee in Fukui Occupational Health Center approved all the design, protocol, and procedures. The Safety and Health Committee within each enterprise, which according to the Industrial Safety and Health Law is composed of employers, industrial physicians and representatives of employees, also approved those.

One thousand one hundred forty-seven workers underwent a health check-up for the THP at Fukui Occupational Health Center between April 1990 and March 1993. All participants were fully informed of the details of measurements by industrial health personnel of the relevant enterprise and the staff of Fukui Occupational Health Center in charge of health examination, and signed the consent form before the examination.

Subjects meeting the following 4 criteria were selected: 1) subjects who underwent a health examination once a year for 2 consecutive years, 2) subjects who did not meet the contraindications for the exercise test in the THP in the first and second years (the first and second tests) and could undergo the exercise test, 3) subjects from whom blood was collected in a fasting state, and 4) subjects who were not receiving any medication or therapy. One hundred twenty-two males and 104 females fulfilled those 4 criteria. Thereafter we excluded 3 males and 17 females whose estimated $\dot{V}O_2max$ on the first or second tests was less than 17.5 ml/kg/min (6), since these values were considered too low because of technical errors or biological variability (7). Consequently, the data of 119 males and 87 females were analyzed in this study. Table 1 shows the number of subjects by job.

Percent body fat, blood pressure, and blood tests

Percent body fat was estimated as follows: first, triceps and sub-scapular subcutaneous fat thickness were measured using an adipometer; next, the percent body fat was calculated using the equations of Nagamine and Suzuki (8). Resting blood pressure and heart rate were measured in the right arm by the auscultation method using a mercury sphygmomanometer after the subject had been sitting for 10 minutes in a chair.

For analysis of blood biochemical components, an automated analyzing system (HITACHI 7150) was used. Serum was separated from blood samples collected in a fasting state. Serum total cholesterol (TCH) and uric acid (UA) were quantified using Autocela CHO-2 and Autocela UA-2, respectively. Serum HDL cholesterol was quantified using Autocela CHO-2 after fractionation of HDL cholesterol using Autocela CHO-2. Blood glucose (BG) was measured using Autocela GLU-2. All reagents were purchased from Daiichi Pure Chemicals Co., Ltd., Japan.

Estimated $\dot{V}O_2max$

Using a bicycle ergometer (CatEye Co., Ltd., Japan, Model EC-1500) with built-in exercise loading protocols (Fig. 1), $\dot{V}O_2max$ was estimated from heart rate responses of the subject. First, the regression was obtained from heart rates and the power output (Watts) at each exercise step in a resting state, and after 3, 6, and 9 minutes. Next, the maximal physical working capacity (PWCmax) was estimated only in subjects who showed a nearly linear relationship between heart rate and exercise load. Then, using the nomogram of Åstrand (9), $\dot{V}O_2max$ (ml/kg/min) was estimated from PWCmax. Electrocardiogram and blood pressure of the subjects were monitored during the exercise, but there were no findings requiring special attention.

In the Resource Manual For Guidelines for Exercise Testing and Prescription (10), Shephard emphasizes the importance of considering individuals of differing body size in the comparison of $\dot{V}O_2max$. He states, “Notice that a low relative $\dot{V}O_2max$ may reflect either a poor oxygen transport or an excessive accumulation of body fat.” In our study, therefore, relative values per kg of body weight were used. Hereafter, the estimated $\dot{V}O_2max$ per body weight is referred to as e-$\dot{V}O_2max$.

Exercise, smoking and drinking habits

A questionnaire on habitual physical activity and amounts of smoking and alcohol consumption over the 30 days before the survey was completed by each subject. The extent of physical activity during the 30-day period was calculated as habitual physical activity with the equation using metabolic equivalents (METs) published by American College of Sports Medicine (ACSM) (11, 12): Habitual Physical Activity (HPA) =METs×duration of physical exercise (hours)×frequency of physical exercise (times/30 days). “MET” is the unit used to estimate the metabolic cost (oxygen consumption) of physical activity. One MET equals the resting metabolic rate, approximately 3.5 ml O_2/kg/min. Certain kinds of exercise done by the subjects in the present study did not have the units as METs determined by ACSM. However, in Japan, Relative Metabolic Rate (RMR) was determined as a unit for more kinds of exercises including those. A equation converting RMR to METs was determined on theory that METs involve both RMR and basal metabolic rate as follows: METs=0.83×RMR+1 (13). When the subject performed multiple types of exercises, the physical activity of each type of exercise was calculated and summed up.

Smokers gave the mean number of cigarettes smoked per day. The cumulative alcohol intake during the 30-day period was calculated in terms of the alcohol content in a large beer bottle (633 ml), one GOU of Japanese sake (180 ml), and one glass of whisky-and-water as 31.8, 28.8, and 16.8 g, respectively.

Statistical analyses

All statistical analyses were performed using the 10.0 J release version of the SPSS statistical package for personal computers (SPSS Inc., Chicago, IL). Differences in the parame-

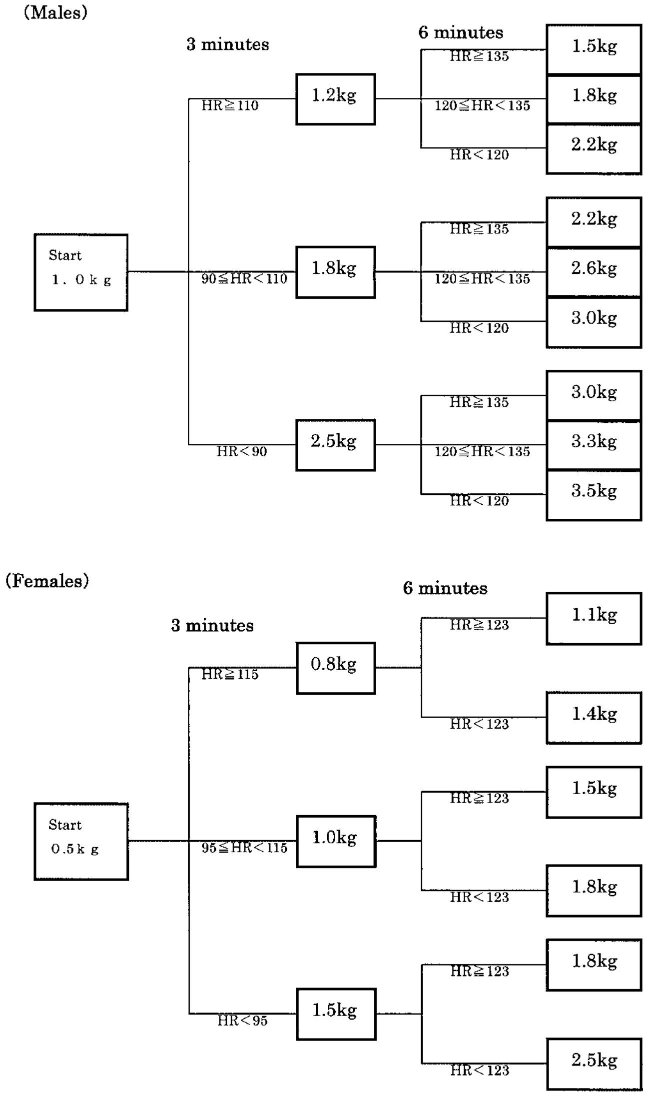

Fig. 1 Protocol* for cycle ergometer test
*** Protocol is selected according to Heart Rate (HR) in the previous stage.**
Exercise time is 9 minutes. HR in this figure is an example of 20-year-old subject. For aged males, the HR was adjusted by revision coefficient (k). k is calculated as follows:
k=(204-0.69×age)/(204-0.69×20)
Males over 50 years old are treated in the same way as females. Males under 20 years old are treated as the 20-year-old group.

ters between the first and second tests were analyzed by the paired t-test. To clarify the factors significantly related to e-$\dot{V}O_2$max as a dependent variable, multiple regression analysis with a stepwise method was performed using age, percent body fat, blood pressure, blood test parameters, HPA, number of cigarettes, and alcohol consumption as independent variables.

To clarify the factors responsible for changes in e-$\dot{V}O_2$max from the first to the second test, multiple regression analysis was performed using yearly changes in all parameters as independent variables.

A probability value of $P<0.05$ was considered significant. All values are expressed as means (SD).

Table 1 Number (%) of subjects by job

	Males	Females
Office work	20 (16.8)	17 (19.5)
Machine operating	41 (34.5)	30 (34.5)
Handwork	16 (13.4)	24 (27.6)
Transportation	22 (18.5)	0 (0)
Customer services and sales	15 (12.6)	12 (13.8)
Others	5 (4.2)	4 (4.6)
Total	119 (100)	87 (100)

Results

Table 2 shows the physical and blood characteristics of the subjects. All parameters were within normal range. Table 3 shows HPA, the mean number of cigarettes smoked per day (Smoking), and the mean alcohol consumption per 30 days (Drinking) of the subjects. In the group including those with an age of over 60, there was 1 man who had 202.5 HPA. He habitually took the running exercise for 40 minutes at a time, 4 times per week.

Table 4 shows the values of e-$\dot{V}O_2$max in the subjects with different habits. A significant difference in e-$\dot{V}O_2$max was observed only between the male groups with and without drinking habits in the second year.

Table 5 shows the results of the multiple regression analysis. In the first test, systolic blood pressure with standard regression coefficient (SRC) as −0.228 and percent body fat (SRC as −0.214) were adopted as significant negative factors for males, and age (SRC as −0.304) was adopted as a significant negative factor for females. In the second test, diastolic blood pressure (SRC as -0.318) was adopted as a significant negative factor and HPA (SRC as 0.229) was adopted as a significant positive factor for males. For females, systolic blood pressure (SRC as −0.389) was adopted as a significant factor in the second year. Cigarettes and alcohol were not adopted as significant factors affecting e-$\dot{V}O_2$max in either males or females. With regard to the yearly changes in e-$\dot{V}O_2$max, changes in the number of cigarettes smoked (SRC as −0.250) were adopted as a significant negative factor in males. For females, yearly changes in percent body fat (SRC as −0.226) were significantly correlated with changes in e-$\dot{V}O_2$max.

Discussion

$\dot{V}O_2$max generally decreases with aging (14). The results of our study showed that age was negatively related to e-$\dot{V}O_2$max in females. Exercise habits have been reported to maintain and improve $\dot{V}O_2$max (15) and HPA assessed in our present study was also positively related to e-$\dot{V}O_2$max in males.

A low $\dot{V}O_2$max, as well as hypertension, hyperlipemia, diabetes mellitus and obesity are risk factors for cardiovascular diseases (4, 16). Also in our study, percent body fat was a significant factor negatively affecting e-$\dot{V}O_2$max in the cross-sectional analysis of males, and so was the amount of yearly changes in females. It is clear that appropriate exercise is effective for maintaining proper percent body fat, blood pressure, and blood glucose (17, 18). In the present study, the mean

Table 2 Physical and blood characteristics of the subjects: mean and standard deviation

	Male (N=119)		Female (N=87)	
	First test	Second test	First test	Second test
Age (yr)	38.3 (14.1)		40.2 (11.5)	
Body fat (%)	15.9 (4.2)	15.6 (3.6)	22.8 (5.6)	23.1 (5.2)
e-$\dot{V}O_2$max (ml/kg/min)	34.7 (8.2)	34.6 (8.7)	27.5 (5.5)	28.6 (7.3)
Systolic blood pressure (mmHg)	130.7 (13.2)	128.5 (13.5)*	120.0 (14.7)	121.0 (15.8)
Diastolic blood pressure (mmHg)	76.4 (7.9)	75.8 (8.8)	70.3 (8.6)	70.3 (8.8)
Serum total cholesterol (mg/dl)	192.7 (34.6)	194.3 (31.2)	191.0 (37.9)	195.1 (39.1)
Serum HDL cholesterol (mg/dl)	49.5 (10.1)	49.7 (12.3)	56.9 (10.9)	56.4 (10.5)
Blood glucose (mg/dl)	88.7 (11.8)	91.8 (12.0)*	86.1 (10.1)	88.4 (15.6)
Serum uric acid (mg/dl)	5.8 (1.2)	5.7 (1.07)	3.8 (1.0)	3.9 (0.9)

* $p<0.05$ for the difference between the first and the second test.

Table 3 Amount of exercise, smoking and drinking in subjects grouped by age: mean and standard deviation

	Males						Females				
Age	20–29	30–39	40–49	50–59	60+	n[a]	20–29	30–39	40–49	50–59	n[a]
First test:											
HPA[b]	28.3 (17.4)	33.2 (12.3)	40.8 (30.3)	20.7 (23.0)	202.5 (0)	30	32.8 (33.1)	47.8 (21.5)	27.5 (18.7)	57.0 (44.4)	18
Smoking (cigarettes/day)[c]	16.7 (7.9)	23.4 (9.4)	19.1 (8.5)	17.1 (5.8)	13.5 (2.1)	70	5.0 (0)	9.3 (5.4)	15.0 (0)		7
Drinking (mg alcohol/30 days)[d]	778 (685)	1220 (933)	1105 (701)	1293 (626)	1244 (483)	78	190 (189)	240 (195)	386 (473)	202 (122)	20
Second test:											
HPA	64.4 (71.1)	22.0 (19.8)	28.0 (18.4)	23.0 (21.8)		22	17.8 (7.4)	44.6 (39.9)	23.0 (5.8)	39.0 (40.7)	17
Smoking (cigarettes/day)	17.2 (9.4)	23.2 (8.5)	20.7 (8.2)	17.2 (6.4)	10.0 (0)	65	6.7 (2.9)	15.0 (0)	15.0 (0)		6
Drinking (mg alcohol/30 days)	579 (660)	1301 (808)	1141 (874)	1189 (699)	786 (174)	77	237 (196)	317 (0)	453 (494)	134 (67)	16

[a] Number of subjects. [b] METs×Exercise time (hour)×Frequency of Exercise (times/30 days).
[c] Mean numbers of cigarettes smoked per day. [d] Alcohol consumption for 30 days (mg/30 days).

Table 4 The estimated maximal oxygen uptake in subjects by exercise, smoking and drinking habits: mean (ml/kg/min) and standard deviation

	Males				Females			
	First test	n[a]	Second test	n	First test	n	Second test	n
Exerciser	32.9 (7.3)	30	36.6 (8.9)	22	28.7 (7.5)	20	29.7 (8.3)	17
Non-exerciser	35.4 (8.5)	89	34.1 (8.7)	97	27.2 (4.9)	67	28.3 (7.1)	70
Smokers	35.6 (8.5)	70	35.2 (9.0)	65	31.4 (6.4)	7	31.2 (4.9)	6
Non-smokers	33.5 (7.8)	49	33.9 (8.4)	54	27.2 (5.3)	80	28.4 (7.4)	81
Drinkers	35.7 (9.0)	78	35.8 (9.3)	77	29.2 (7.0)	20	29.3 (6.7)	16
Non-drinkers	32.8 (6.1)	41	32.3 (7.0)	42	27.0 (4.9)	67	28.5 (7.4)	71

[a] Number of subjects. * Significant difference was observed in parenthesis ($p<0.05$).

Table 5 Stepwise multiple regression analysis of estimated maximal oxygen uptake (dependent variable) with age, body fat, systolic blood pressure, diastolic blood pressure, serum cholesterol, serum HDL cholesterol, blood sugar, serum uric acid, habitual physical activity, number of cigarettes smoked and alcohol consumption (independent variables) in 119 males and 87 females

	Males			Females		
	R[a]	Significant variables	SRC[b]	R[a]	Significant variables	SRC[b]
First year	0.327	Systolic blood pressure	–0.228*	0.304	Age	–0.304**
		Percent body fat	–0.214*			
Second year	0.370	Diastolic blood pressure	–0.318*	0.389	Systolic blood pressure	–0.389**
		Habitual physical activity	0.229*			
Yearly changes	0.250	Smoking	–0.250**	0.226	Percent body fat	–0.226*

[a] Coefficient of determination. [b] Standardized regression coefficient. * $p<0.05$, ** $p<0.01$.

of HPA for females was less than that for males. It can be said from this finding that females should make efforts to reduce the percent body fat by appropriate exercise.

Montoye et al. (16) reported that after the influences of age, weight, skin fold thickness, and drinking habits were removed, smokers clearly had a decreased $\dot{V}O_2$max. A negative influence of smoking on $\dot{V}O_2$max (19) and a positive effect of giving up smoking on $\dot{V}O_2$max (20) have been reported.

In our study, the mean number of cigarettes smoked per day by male smokers slightly increased from 18.7 in the first test to 19.3 in the second test. Similarly, the mean number of cigarettes smoked by female smokers slightly increased from 8.9 in the first test to 10.8 in the second test. These yearly changes in the number of cigarettes smoked were shown by individuals to affect e-$\dot{V}O_2$max in males. In this regard, our study is the first reporting that an increase in the number of cigarettes smoked negatively affects the yearly changes in e-$\dot{V}O_2$max, even for a one-year duration, by individuals. To prevent a reduction in e-$\dot{V}O_2$max, it is most important that, in addition to education on smoking cessation, all enterprises should encourage smokers to reduce the number of cigarettes smoked per day.

The relationship between drinking habits and smoking habits is a matter of further concern. Montoye et al. (16) reported that when the relationships were corrected for age, weight, skin fold thickness, and smoking habits, the heaviest drinkers and the non-drinkers had the lowest e-$\dot{V}O_2$max and the moderate drinkers had the highest e-$\dot{V}O_2$max, at least in the younger age groups. In the first and second tests in our study, the mean e-$\dot{V}O_2$max was significantly higher in male drinkers than in non-drinkers. Nevertheless, the multiple regression analysis did not show any significant effects of alcohol on e-$\dot{V}O_2$max.

In our study, smokers were found to drink more than non-smokers and showed a greater decrease in e-$\dot{V}O_2$max. As for our experience, some smokers may be drinking too much compared to non-smokers. Accordingly, it may be necessary to instruct enterprise workers via the THP to reduce not only smoking habits but also drinking habits if they drink too much.

Acknowledgments

The authors thank Professor Masayuki IKI, M.D., Ph.D., at Kinki University School of Medicine, Professor Toshimitsu Ebisu, Ph.D., at Fukui University, and Kenich Kamiya, M.D., Ph.D., at Fukui Red Cross Hospital for their valuable comments on the paper and encouragement to the authors.

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