The effects of habitual cigarette smoking on maximal work capacity and pulmonary function

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Abstract. *To evaluate the effects of cigarette smoking on some of the cardiorespiratory responses to maximal work as well as on pulmonary functions, a group of male adult subjects, 5 smokers and 5 nonsmokers, was studied. Work consisted of a bicycle ergometer test. For the determination of lung functions, Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second ($FEV_{1.0}$) were tested. $FEV_{1.0}$%, the ratio of $FEV_{1.0}$ to FVC was also calculated. A resting carboxyhemoglobin (HbCO) level in the smoking group was significantly ($P<0.001$) higher than that in the nonsmoking group. No significant differences were seen in resting HR, systolic and diastolic blood pressures between smokers and nonsmokers. The percentage of body fat (%fat) in the smoking group was larger than that in the nonsmoking group. In the maximal values through the bicycle ergometer test, oxygen uptake, and ventilation in the nonsmoking group were significantly ($P<0.05$) higher but HR and systolic blood pressure were not significantly different as compared to those in the smoking group. During recovery after the maximal work, there were no significant differences in HR changes between the groups whereas oxygen uptakes were significantly lower in the nonsmoking group than those in the smoking group. Pulmonary function tests performed on the two groups revealed normal results for each group. No significant difference was observed in FVC. However, the higher values of $FEV_{1.0}$ and $FEV_{1.0}$% in nonsmokers than those in smokers were significant. These findings suggest that habitual cigarette smoking lowers maximal work performance as well*

as pulmonary function.

Cigarette smoking remains a prominent health issue among adults. Long-term cigarette smoking is associated with increased risk of almost every known chronic health problem, including lung cancer[18], obstructive pulmonary disease[4], coronary heart disease[17], hypertension, and stroke.

In addition to being a public health problem, cigarette smoking has been noted to affect exercise performance. It has been well noted that adult smokers, even when they are apparently healthy, often perform poorer on exercise tests, especially on distance run than nonsmokers.

Tobacco contains about 200 different components. Some of these are highly dangerous in larger doses, but most of them are present in the smoke in concentrations so small that they have no measurable effect on the human organism. Research has primarily focused on 3 compounds in cigarette smoke: carbon monoxide (CO), nicotine and the smoke particles (tar). The effect of smoking during exercise is most often related to those three components. .

Most interest has been focused on the effect of CO on working capacity. The oxygen capacity of the blood is decreased corresponding to the amount of CO bound to the hemoglobin. This may tend to decrease a subject's aerobic work capacity. This has been confirmed by several investigators by introducing CO in various concentrations to the air breathed by subjects[13]. Furthermore, the nicotine and the smoke particles, which influence the airways and the lungs, may also affect aerobic work capacity. Nevertheless, aerobic work capacity studies of smokers and nonsmokers have yielded mixed results[7, 9, 12, 14]. It was the purpose of the present study to examine the cardiorespiratory effects of habitual smoking to maximal exercise and the lung functions.

Methods

Subjects

Ten moderately active male adults volunteered to participate in this study. Five were habitual smokers and five never smoked. All smokers

Table 1. Physical characteritics of the men in the nonsmoking and smoking groups

	Group			
Variable	Nonsmoking		Smoking	
Age (yrs)	37.6	(3.4)	39	(3.5)
Height (cm)	173.4	(2.1)	172.8	(4.1)
Body mass (kg)	69.5	(5.4)	69.5	(4.9)
Body fat (%)	17.5	(3.4)	21.3	(3)*
Resting HR (bpm)	60.6	(11.5)	73.2	(13.6)
SBP (mmHg)	119.6	(9.6)	122.4	(15.2)
DBP (mmHg)	78	(3.7)	69.6	(11.4)
Hct (%)	42.9	(2.7)	42.9	(1.7)
Hb (mg/dl)	14.2	(1.0)	14.1	(0.9)
%HbCO	0.376	(0.007)	6.033	(1.027)***

Values are mean (SD); $^{*}P<0.05$; $^{***}P<0.001$
SBP and DBP; systolic and diastolic blood pressure, respectively
Hct and Hb: hematocrit and hemoglobin, respectively
%HbCO: percentage carboxyhemoglobin

in the group had smoked one or more packs of cigarettes per day for at least 5 years. The physical characteristics of the subjects are given in Table 1. All subjects were asked to sign a written informed consent after they were informed of the testing procedures.

Test Protocol

The subjects reported to the lab after abstaining from eating for at least 8 hours, and for the smokers, abstaining from smoking for the past twelve hours. Upon reporting to the lab height and body mass were measured. Body fat (%Fat) was also measured by using impedance technique (QUANTUM RJL System, Clinton Twp, MI). After the measurements, lung function tests, Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1) were recorded for each subject using a spirometer (Fukuda). FVE_1%, the ratio of FEV_1 to FVC was also calculated for each effort. After demonstration, the tests were conducted in the standing posture with using nose clips. ECG leads were attached.

The subjects then rested quietly seated on a chair. After 10 min of rest, the resting heart rate (HR_{rest}), blood pressure, venous blood parameters and oxygen uptake (VO_2) were determined. Once resting measurements were completed, each subject performed a ramp exercise test to exhaustion. Exercise was performed on a Lode electromagnetically braked cycle ergometer with the work rate controlled by microcomputer (Corival 1000). The cycle ramp test was initiated following 5 min of 50 Watt-lode pedaling, and the work load was then increased by 20-Watt every minute. The subjects maintained a pedaling frequency of 50～60 rev/min. The test was continued till the subjects reached a point of exhaustion or could no longer maintain the pedaling frequency when the load was increased.

HR and VO_2 were recorded during the bicycle work and during the 10 min recovery period after exercise. In addition, four minutes after exercise a venous blood sample was obtained from an antecubital vein for lactate analysis.

Instrumentation

Systolic and diastolic blood pressures and HR were determined by automated sphygmomanometer (CM-4001, Kyokko Bussan) and electrocardiograms recorded by chest leads before, during the cycle test and for the 10 min after work. Measurement of oxygen uptakes was also done using Oxycon Gamma (Mignhardt). A venous blood sample was drawn from an antecubital vein for determination of hematocrit (HCT), hemoglobin (Hb) and lactic acid (HLa). Hct was determined using a capillary hematocrit reader while Hb was determined by the standard spectrophotometric hemoglobin cyanide method. Blood lactate was determined using YSI 1500 Sport Lactate Analyzer (Yellow Spring Instruments, Ohio). For the determination of blood percentage of carboxyhemoglobin (%HbCO) levels, a spectrophotometry was used.

Statistical analyses

The statistical analyses were performed using a SPSS statistical package for personal computer[(16)]. Mean values and standard deviations of all variables from the 10 subjects were calculated. Differences between the smoking and nonsmoking groups were analyzed by the Student **t**-test. Significance was set at the 0.05 level of confidence.

Results

Subject characteristics. Average values of the measured parameters are given in Table 1. There were no significant group differences on the matching variables of age, height, body mass, resting HR, blood pressures and hematological parameters of Hct and Hb. However, mean %fat in the smoking group was significantly higher than that in the nonsmoking group ($P<0.05$). In addition the level of %HbCO in the smoking group was nearly as 16 times high as the level of %HbCO in the nonsmoking group.

Physiologic responses to maximal work. Mean values (1SD) from the maximal work tests in the smoking and nonsmoking groups are presented in Table 2. Maximal oxygen uptake (VO_{2max}) and maximal ventilation (V_{Emax}) were higher in the nonsmoking group than in the smoking group ($P<0.05$). Post exercise venous blood lactates averaged 7.7 mmol/L in smokers, significantly greater than the nonsmokers (6.8 mmol/L). On the other hand, no significant differences were noted in maximal HR and maximal systolic blood pressure between the two groups.

Figure 1a shows mean values of the HR for smokers and nonsmokers. The HR changes during the exercise period were similar in the two groups. However, the smoking group had a tendency toward higher values throughout the recovery period. The mean values for the 5th

Table 2. PMaxiimal values of different variables measured during a maximal test in the smoking and nonsmoking groups

Variable	Group			
	Nonsmoking		Smoking	
Maximal VO_2 (ml/Kg/min)	48.1	(6.7)	43.7	(4)*
Maximal HR (bpm)	189.4	(5.8)	190.4	(5.1)
Maximal V_{Emax} (L/min)	122	(23.1)	95.2	(13.5)*
Maximal SBP (mmHg)	184.4	(9.2)	185	(10.6)
Peak HLa (mmol/L)	6.78	(0.57)	7.70	(0.58)*

Values are mean (SD); $^*P<0.05$

VO_2: oxygen uptake; LA: venous blood lact; VE: ventilation (BTPS)

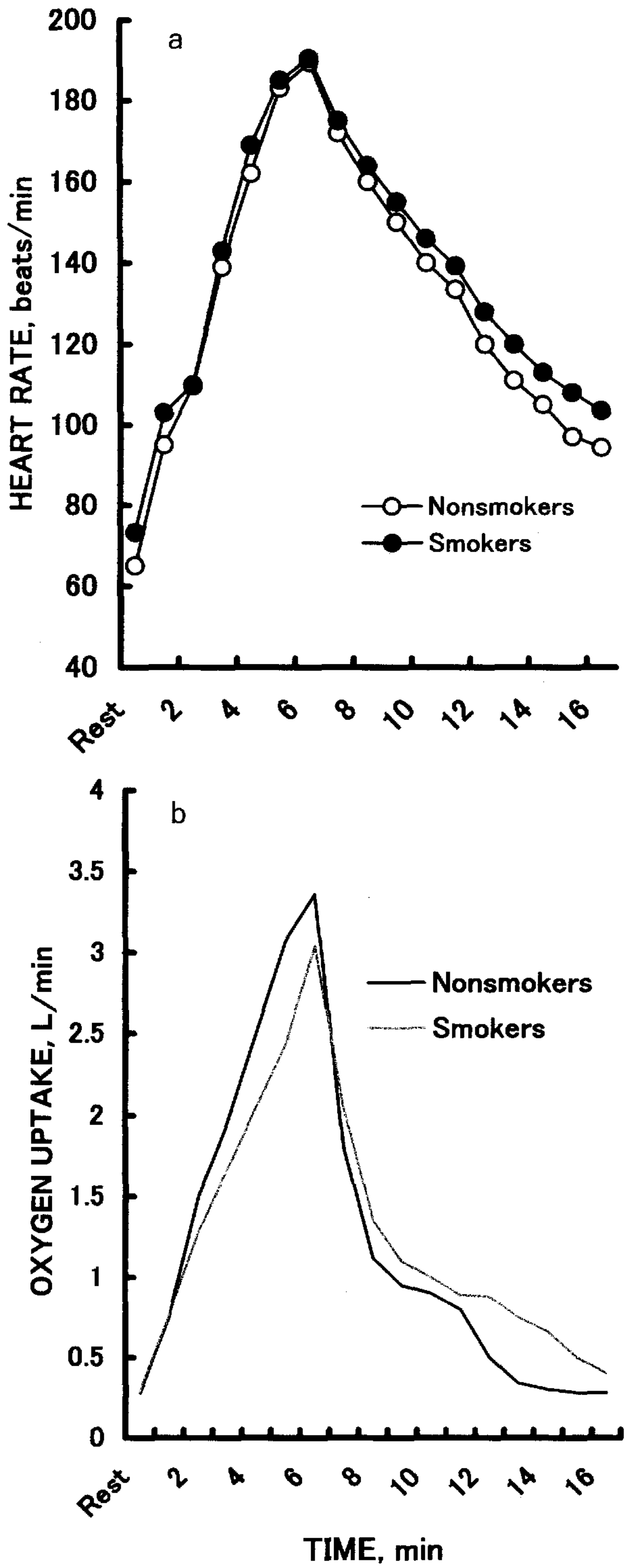

Figure 1. Heart rate (a) and oxygen uptake (b) in the smoking and nonsmoking groups during graded maximal exercise and recovery period.

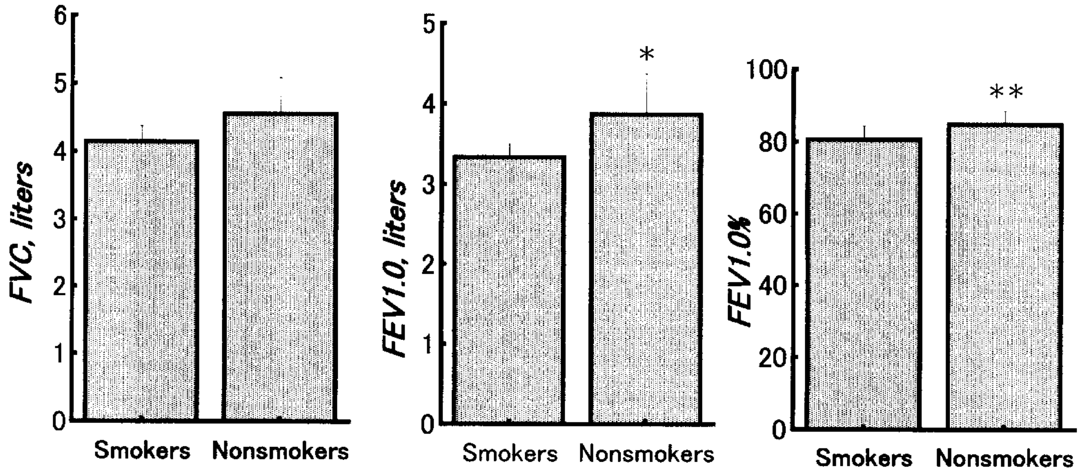

Figure 2. Spirometric data for the smoking and the nonsmoking groups. *$P<0.05$; **$P<0.01$

min and 10th min of recovery period were 133.5 (12.7) for the nonsmokers and 139.3 (13.2) for the smokers; 94.3 (9.3) for the nonsmokers and 103.5 (10.6) for the smokers, respectively. The differences are not statistically significant.

Figure 1b represents the mean values of oxygen uptake for smokers and nonsmokers. The values for the entire work and recovery period are plotted. Significantly ($P<0.05$) higher values were seen in the nonsmoking group during the last half period of work whereas during recovery the mean rate of oxygen uptake at several points of time interval was greater for smokers than for nonsmokers. The oxygen debt was therefore greater for smokers.

As Figure 2 demonstrates, no significant difference was observed in mean FVC between the smoking and nonsmoking groups. However, $FEV_{1.0}$ in the smoking group was significantly lower ($P<0.05$) than that in the nonsmoking group, and consequently $FEV_{1.0}$% was also significantly lower ($P<0.05$).

DISCUSSION

The results of the present investigation support the contention that habitual cigarette smoking lowers maximal work capacity and pulmonary function.

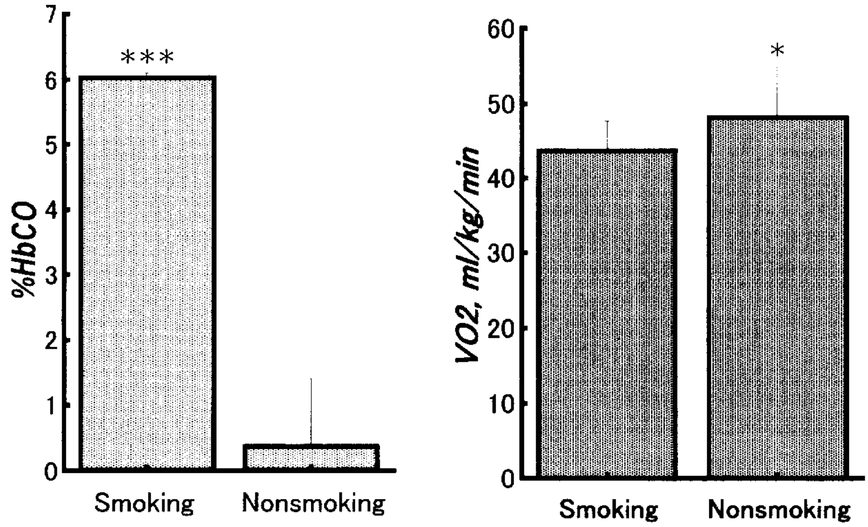

Figure 3. Blood percantage carboxyhemoglobin levels (a) and maximal oxygen uptake (b) for the smoking and nonsmoking groups.
*$P<0.05$; ***$P<0.001$

The most striking difference between smokers and nonsmokers in the present study was the blood percentage HbCO levels as shown in Table 1 and Fig. 3. These values were 6.0% and 0.4% in smokers and nonsmokers, respectively. The lower VO_{2max} in the smoking group may be attributable to the elevated carbon monoxide binding with the hemoglobin (HbCO) because the oxygen carrying capacity is reduced. Horvath et al.(6) concluded that VO_{2max} reduction due to the presence of HbCO in blood is linear in the range of 4%～35% HbCO. In addition, Lamb(10) has suggested that a maximal levels, up to 90% of the oxygen carrying capacity may be needed. If the smoking reduces this capacity, the muscle cannot attain the high rate of aerobic metabolism unless cardiac output is further increased. The present results that maximal HR was not affected by smoking, but VO_{2max} was significantly affected, were in good agreement with a previous study(5) in which percentage of HbCO in the smoking subjects was identical to that of our smokers. Since maximal HR in this study were similar (190 vs 189 bpm) between the smoking and nonsmoking groups, the cardiovascular system seemed to be maximally taxed. Therefore, high percentage of HbCO in the smoking group adversary affected reducing aerobic capacity by interfering with oxygen carrying capacity. Such interpretation to the reduced VO_{2max} of the smoking group in this study is supported by previous studies where it had been shown that VO_{2max} was unchanged when HbCO levels were approximately 2.7%[15], but was reduced by 7 and 38% when the levels of %HbCO were 4.3%[6] and 7.0%[3], respectively. Thus studies concerning the effects of acute cigarette smoking upon aerobic capacity have yielded relatively consistent results[8, 5, 13]. Among the subjects in their studies, acute smoking was noted to increase pre-exercise %HbCO from 1.8 to 6.6. Consequently, VO_{2max} was significantly depressed. Even at a young age, cigarette smoking was associated with significant detrimental effects on cardiopulmonary function and exercise tolerance[11]. This could be explained by impaired oxygen transport capacity as a result of elevated %HbCO. Although finding in the present study that VO_{2max} was lower in smokers than in nonsmokers is in agreement with a large population study by Knapik et al.[9], it is not in agreement with other studies[12, 14]. Such inconsistency among the various studies regarding the comparison of VO_{2max} between smokers and nonsmokers cannot be fully explained.

It was curious that there was no significant difference in the Hb and Hct between the smoking and nonsmoking groups because it is known that the higher levels of HbCO in smokers had a hemopoietic effect.

Although we did not measure oxygen debt directly, we did find higher levels of lactate in the smoking group (Table 2). This greater lactate at a lower VO_2 indicates a greater reliance on anaerobic metabolism. Such observation could be confirmed with another finding depicted in Fig. 1b that the mean rate of oxygen uptakes during recovery was greater for the smoking group than for the nonsmoking group. The oxygen debt was therefore, greater for the smoking group.

It is interesting to note that the heart rates during severe workloads were not different between the groups. This finding is in line with findings by previous studies[1, 8]. Klausen et al.[8] suggested for the interpretation that an inhibitory effect of smoking on HR during near maximal and maximal works, but HR is increased at lower levels of exercise intensity. It remains uncertain that resting HR and blood pressure were not significantly affected by cigarette smoke in this study although the resting HR in the smoking group tended to be higher than that in the nonsmoking group whereas other studies[1, 8] did demonstrate the higher values of the parameters in smokers.

One of the notable differences between the smoking and nonsmoking groups was ventilatory function. Although we did not measure nicotine and smoke particles, the significantly greater value in VE_{max} ($P<0.05$) of the smoking group (Table 2) may be due to a smaller tidal volume and the lower ventilatory efficiency in smokers. Furthermore, the lower $FEV_{1.0}$ ($P<0.05$) and $FEV_{1.0}\%$ ($P<0.01$) values of the smoking group (Fig. 3) could be presumed due to involvement of smaller airways obstruction. The lower pulmonary function of the smokers in the present study is in accordance with a previous study by DE and Tripathi[2]. In the study, Peak Expiratory Flow Rate (PEFR) was recorded in addition to FVC, $FVE_{1.0}$ and $FEV_{1.0}\%$. It was reported that PEFR of smokers was significantly lower than that of nonsmokers.

In conclusion, although the number of subjects in the present study was relatively small, the results imply that cigarette smoking has a significant detrimental effect on exercise performance, especially, by reducing maximal aerobic power. It has been demonstrated that the CO-content of the blood is in the main responsible for the reduction in aerobic power.

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最大作業能力と肺機能に及ぼす習慣的喫煙の影響

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要　約

被験者　長年にわたる喫煙習慣が最大作業能力および肺機能に及ぼす影響を検索するために，最低5年の喫煙習慣を有する健康な男性5名〔平均年齢＝39（3.5SD）歳〕と喫煙経験を持たない健康な男性5名〔平均年齢＝38（3.4)〕が被験者として参加した。両群間に身長と体重の差は認められなかったが喫煙群の体脂肪（%）は有意に高かった（21.3 vs 17.5%)。

結　果　安静時の心拍数（HR)，血圧，ヘマトクリット（Hct）値，ヘモグロビン（Hb）濃度の測定では両群間に有意な差は見られなかった。しかし，喫煙群の血中一酸化炭素ヘモグロビン（%HbCO）濃度は非喫煙群の16.3倍（6.03 vs 0.37)（$P<0.001$）であった。肺機能テストに肺活量（FVC)，1秒量（$FEV_{1.0}$）が測定され，そこから1秒率（FEV1.0%）が求められた。FVCに両群の有意差は見られなかったが，喫煙群は$FEV_{1.0}$および$FEV_{1.0}$%で有意に低い値を示した。自転車エルゴメターを用いた最大運動負荷テスト（ランプ負荷漸増）の結果，両群間に最大酸素摂取量（VO_{2max})，最大換気量（V_{Emax})，ピーク血中乳酸（HLa）値に有意差が見られたが最大収縮期血圧，最大心拍数に有意差は見られなかった。すなわち，喫煙群のVO_{2max}とV_{Emax}は非喫煙群より低く（43.7 vs 48.1mg/kg/min; 95.2 vs 122L)，ピークHLaは逆に有意に高値であった（7.70 vs 6.78mmol/L)。最大運動後の10分間回復期における喫煙群の分時HR回復は非喫煙群より緩慢ではあるものの統計的な有意差は見られなかった。しかし，回復期VO_2では喫煙群に有意に高かった。

考　察　喫煙習慣者の高い血中一酸化炭素濃度は明らかに酸素運搬能を低下させ，その結果有酸素性作業能力を示すVO_{2max}が有意に低く示された。

酸素負債の測定は行われなかったものの，回復期の酸素摂取量の変動から最大作業に対する喫煙者の酸素負債は非喫煙者より大きいことが容易に考えられ，併せて喫煙群の有意に高い運動乳酸値から，最大かそれに近い運動時においては非喫煙者に比べて無酸素性代謝の関与が大きいことが推測される。このことが最大有酸素性作業能力の低下につながっているものと考えられる。また喫煙群の低い VE_{max} および $FEV_{1.0}$ または $FEV_{1.0}$%から，慢性的なたばこ煙粒子物質の暴露による気道の狭窄による換気抵抗もしくは空気流速の低下が考えられよう。

結　語　喫煙習慣者の有酸素性作業能は非喫煙者と比べて有意に低下する。